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COAL GEOLOGY: AN OPPORTUNITY FOR RESEARCH AND STUDY.[1]

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ABSTRACT.

Coal Geology is conveniently divided into two fields, one which concerns the geology of coal beds, the other the geology of coal itself. In the first field study and research have to do with coal resource and related activities, with mining geology, with the natural history of coal beds; in the second field study is concerned with the botanical, petrographic, and chemical constitution of coal. It is particularly desirable that chemical studies be related to the geological factors that produced coal from pre-coal material and the subsequent metamorphism of coal. Systematic geological training, instruction, and research in all these branches of coal geology have been much neglected in the academic field.

INTRODUCTION.

THE nature of research in the geology of mineral substances varies among these substances. Conventional geological considerations are of prime importance, and research bearing on these considerations provides the fundamental knowledge that facilitates the discovery and recovery of ore deposits and water and oil resources.

With respect to coal the case is different. The problems of coal occurrence and distribution are solved by careful stratigraphic and mapping methods. Somewhat more exacting are those geological problems involved in the achievement of safe and easy recovery of the coal.

But beyond all considerations involving occurrence, supply, and recovery of the coal resources is the fundamental geological problem of the character of the coal material itself, the solution of which is essential to the satisfactory classification and description and the effective and complete utilization of our coal resources. To achieve this understanding the geological factors that effect diagenesis, incoalation, coal metamorphism, and coal classification must be recognized and evaluated, the nature of the chemical changes resulting from the varying geological influences must be specifically determined, and the variations in chemical constitution and physical attributes must be correlated.

[1] Published by permission of the Chief, Illinois State Geological Survey, Urbana.

NATURE OF COAL RESEARCH.

This article reviews the general field of coal geology and points out some of the possibilities for geological research, particularly of a basic or fundamental character, that exist in this field.

Coal geology may be conveniently partitioned into those fields of knowledge and inquiry that concern the geology of coal beds and those that concern the geology of the coal material itself. The geology of coal beds consists of knowledge relating to the discovery and delineation of coal resources, the stratigraphic and structural conditions, and the geologic and economic conditions that affect the mining operation. The geology of coal material, on the other hand, consists of knowledge relating to the nature and origin of its physical heterogeneity in composition and properties, of its variations in chemical composition and properties, and of those geological conditions whereby these several variations were produced. These various topical sections of coal geology are discussed briefly.

COAL RESOURCES STUDIES AND ACTIVITIES.

Coal resource inventories require careful and detailed stratigraphic studies and mapping by technically trained geologists. The detailed stratigraphic succession of few, if any, of our American coal fields is thoroughly understood, thereby denying us complete understanding of the conditions of coal bed occurrence and origin. Furthermore, at many localities faulting and folding of the coal measures make necessary the skillful use of stratigraphic methods for the identification of coal beds. The growing usefulness of fossil spores obtained from coal beds by maceration methods is beginning to give the coal beds importance in their own right as stratigraphic key beds.

The mapping of coal resources commonly provides data for the construction of structure maps on one or more coal beds. Such maps have proved helpful not only for indicating the position and distribution of a particular coal bed, but also for indicating the nature and potency of the geological vicissitudes to which the coal beds have been subjected. They also provide a plane of stratigraphic reference, and in oil and gas regions they may indicate the position of structures favorable for the accumulation of oil and gas.

Of much importance in fundamental studies is the information concerning the characteristics of coal beds and the relationship of coal beds to their associated strata; these data have been largely supplied by field geologists engaged in coal resource studies. Discriminating and accurate description of coal beds as observed in the field are essential to a thorough understanding of coal bed deposition and coal metamorphism. It would be a serious mistake to assume that all variations in coal bed characteristics are known and catalogued so long as large bodies of coal have not been carefully described.

COAL-MINING GEOLOGY STUDIES.

Successful coal recovery requires an understanding of the characteristics of the strata above and below the coal bed being exploited. This is a phase of

geology much neglected and too lightly regarded in academic geology curricula. Nor is this field of geology adequately supported by observational and experimental data. Geologists engaged in coal resource inventories are commonly unfamiliar with the behavior of different types of roof and floor materials in the mining process and hence are unable to evaluate a particular coal deposit either from the character of outcropping associated beds or from diamond drill cores, in the light of prevailing mining practice. Consequently, opinion is commonly divided between geologists and practical mining people as to the economic value of a coal reserve.

There is also an almost complete lack of experimentally established data on the strength of rocks such as commonly compose the coal measures in various coal fields of this country. This lack of knowledge includes uncertainty as to the extent to which the various accordant or discordant stratigraphic relationships of successive strata of different lithologic composition affect the strength of the sedimentary mass associated with the coal beds. Nor, as previously stated, do geologists usually possess a knowledge of the conventional mining methods used in supporting rocks of various strengths and solidity.

The studies which must eventually be made to determine the forces that cause mine roof and floor failures will probably provide information about the nature and degree of the forces that cause the metamorphism of coal.

THE NATURAL HISTORY OF COAL BEDS.

The natural history of coal beds, particularly as concerns their origin, has occupied the attention of geologists almost from the beginning of the science. Coal geology would be incomplete without consideration of the origin of coal beds, the nature of the plants that contributed to the coal beds of various ages, the story of the events and conditions that favored plant growth, the preservation of plant débris in various degrees, and its burial and alteration to coal These are geological processes effective as soon as the plant substance becomes incorporated in the coal swamp débris, with biological agencies effective to a greater or lesser degree until burial is accomplished and possibly for some time thereafter. An understanding of the natural history of a coal bed requires knowledge of the sedimentary conditions of the various strata associated with the coal beds and of the various biological and geological factors that effect plant disintegration on the one hand, and preservation, burial, and geological maturation on the other. It is desirable for early achievement of important and comprehensive results that the problem of coal bed origin be definitely correlated with problems related to coalification in general to avoid irrelevant investigations. Among the numerous problems concerning coal bed origin which have a bearing on the general problem of coal constitution are the following:

1. Natural history of underclays and their significance as soils.
2. Origin of coal beds of different type: Cannel, algal, bright banded, and splint coals.
3. Nature and origin of laminations and banding in coal beds.

4. Time involved in coal bed accumulation and in coal bed formation (incoalation).
5. Original thickness of coal beds.
6. Sedimentary equivalent of coal beds.
7. Origin of isolated shale lenses in coal beds.
8. Effect of the lithology of superimposed sediments upon the kind and rate of coalification.
9. Origin and development of cleat and cleavage.
10. Time and nature of mineral infiltration of calcite, kaolinite, and pyrite.
11. Origin and occurrence of pyrite (and marcasite) in coal beds.
12. Geological rôle of soluble humic acids found in peat waters.

COAL CONSTITUTION STUDIES.

Closely related to the natural history of coal beds are studies in the constitution of coal that have been carried out in the field of coal botany, coal petrography, and coal chemistry. Such investigations have to do with the coal material and attempt to determine the physical properties and chemical and physical make-up of the coal. These studies are more fundamental than those listed under previous sections only in the sense that they are primarily concerned with coal itself.

Studies in the Botanical Constitution of Coal.—From a botanical point of view coal is an aggregate of fossil plant material of which the components are individually more or less recoverable and identifiable as discrete organic entities or structures. It is thus possible to resolve coal into various categories of plant parts or phyterals without attempting rigid botanical classification. Thus the coalified woody material, other than fusain, but including bark, has been grouped under the general category of *anthraxylon* (13, 15).[2] The non-woody material, on the other hand, which is largely finely fragmentary is all classified as attritus. But within attritus, in the thin sections of some coals, it is possible with the aid of the microscope to differentiate a variety of fossil entities representing spores, sporangia, waxes, resins, cuticles, and other minute organic structures as well as minute fragments of humic or woody matter.

The possibilities of botanical research of various kinds in connection with the material present in beds are extensive. For example, recently the usefulness of spores as index fossils in the coal measures of Illinois has been explored (2) with promising results. Other resistant plant parts, such as cuticles, may have a similar stratigraphic use, but they are in general inherently less promising than spores.

In some coal beds coal-balls are relatively common (5, 6) and these provide many well-preserved plant fossils representing the same kinds of plants that compose the coal beds but in uncompressed or only slightly compressed condition, so that the detailed structure of the coal-making plants can be readily discovered. Considerable quantities of such material have been col-

[2] Numbers in parentheses refer to Bibliography at end of paper.

lected in Illinois, Indiana, and Iowa and are now available for study at various universities.

Botanical constitution of coal has for some time been regarded favorably as the key to and basis of variations in coal type, hence as of fundamental importance in determining the specific characteristics of coal as indicated by variations in physical properties, chemical composition, and in combustion, carbonization, and other behavior characteristics. Evidence seems to indicate that the rate and process of incoalation (coal formation) varies among the different classes of botanical substance contributing to the coal bed (9).

Chemical studies (17) indicate that there are chemical differences between the humic and waxy substances in individual coal beds, at least in coals of relatively low rank.

The importance of botanical research in coal is such as to merit the attention of a few geologists with botanical training or botanists with geological training. It is desirable to know all that can be learned of the botanical composition of coal. Only as the possibilities of variation in coal arising from variation in botanical constitution are realized can the effect of geological influences in coal formation and coal metamorphism be evaluated. Certain studies in the chemical constitution of coal may require much closer correlation with botanical data than has been generally achieved.

Petrographic Constitution of Coal.—Coal petrography, as it is commonly understood, consists of little more than a description and classification of coal material in terms of what Stopes (11) designated the four banded ingredients.

The original definitions of the banded ingredients were based upon megascopic criteria and the gross aspects of banded bituminous coal. Subsequently the definitions were modified, in line with certain megascopic considerations, until the Stopes system of coal petrography has become inextricably involved with microscopic and botanical qualifications that detract considerably from its usefulness or at least complicate its application.

The petrographic system of coal description has been further complicated by the superimposition of a quasi-mineralogical framework upon the original simple megascopic subdivision (12). This development follows from the desire to regard the coal ingredients as rock types each of which is composed of a characteristic mineral component just as igneous rock types are composed of characteristic minerals. These hypothetical pseudo-mineralogical substances have been designated by the term maceral (12). The maceral concept has been widely adopted for descriptive purposes, especially by European coal geologists. Since these so-called "mineral" substances are obviously organic entities or fragments of such entities, it was suggested by the writer (1) that the term phyteral, as a general name for such plant entities in coal, was preferable to maceral for designating coal components identifiable only as a plant entity. The composition of the phyteral is implied by its identity. The term maceral actually does no more than this although there is the implication that it does more. Unfortunately the introduction of this botanical term has not displaced the use of the term maceral, and we find phyterals grotesquely described as consisting of a particular maceral, an entirely unnecessary and redundant elaboration.

Fusain.—Among the petrographic banded ingredients fusain is an important and conspicuous element. Those workers who base their determination on botanical considerations also recognize the presence of fusain (16), so that fusain, as well as anthraxylon and attritus, is regarded as one of the components of banded coal. It is regarded, however, not as a botanical component, but as a petrographic unit. The botanical categories set up by Thiessen were accordingly burdened with a component describable only in petrographic terms. Fusain was adopted by Stopes as one of the four petrographic ingredients and the terminology proposed by Stopes conforms in general to that previously employed by the French (11, p. 472).

Fusain exists in beds, lenses, aggregates in various form, and of particles greatly varying in size and degree of dissemination, down to those of microscopic dimensions. It is possible that the so-called opaque matter of Thiessen (14) characteristic of splint coals or durain may consist of finely divided fusain. This material has been designated by the maceral name micrinite, whereas the maceral composing fusain is called fusinite. The weakness of the maceral concept is revealed in the uncertainty as to the character of either micrinite or fusinite as hypothetical substances, so that it is impossible to differentiate them.

Petrographic Method of Coal Description.—Petrographic concepts have been regarded as less fundamental for purposes of coal description and classification than concepts based upon microscopic and botanical considerations. Nevertheless, the petrographic method of coal description, even in its present unsatisfactory technical status, owing to inexact and incomplete definition, has considerable usefulness as a tool of coal research in defining the physical characteristics of coal. The megascopic distinctions between different ingredients of the coal bed are valid, provided certain arbitrary, clearly defined standards of differentiation are observed. Detailed petrographic profiles of a coal bed in terms of the banded ingredients are useful in appraising its amenability to various preparation practices or to selective mining, in order to maintain a uniform product. It is particularly desirable to have such profiles prepared from cores when a virgin coal field is being explored. It is believed that they have an importance comparable to that of chemical analyses of such cores. Unfortunately drilling practice too often does not provide the skill necessary to obtain cores of the quality necessary for the preparation of such profiles.

Petrographic analyses (7) or assays of broken coal are essential when coal is to be used for hydrogenation, since the highly carbonized material—fusain and opaque matter—detracts from the usefulness of coal for hydrogenation purposes. Actually far too few such assays have been made to permit positive conclusions as to their general value, or even to be certain as to the ultimate usefulness of the distinctions applied.

CHEMICAL CONSTITUTION OF COAL.

Elementary Analysis.—The oldest and simplest method of determining the composition of coal was by means of the elementary or ultimate analysis. In general this form of analysis provides, by direct determination, values for

the amount of hydrogen and carbon in the combustible material composing coal, oxygen being a residue, the amount of which is determined by difference and therefore values for oxygen are somewhat less accurate. Differences in the combustible portion of coal, that is the mineral matter-and-moisture-free coal arise chiefly from variations in oxygen content, the amount of oxygen decreasing progressively with increase in rank. This generalization may not apply to coals beyond the bituminous rank. Differences among coals may also exist because of variations in the quantity of waxy and resinous material present, but the nature and extent of these differences are not well known. Similarly variation in the quantity of fusain present undoubtedly affects the elementary composition.

There is apparently a change in the relationship of carbon and hydrogen as coal advances from bituminous to anthracite rank, so that it is probable that anthracite and bituminous coal should be compared on some basis fundamentally different from that upon which comparison of two common types of bituminous coal is made. These relationships require investigation.

Commercial Type of Analysis.—To meet commercial requirements there has been developed what is known as the "proximate" method of coal analysis. The proximate analysis when accompanied by determinations of sulphur content and of calorific value provides the standard criteria for differentiating coals of various ranks by the application of certain empirical rules. Such distinction is based upon samples representing the whole bed collected under standard conditions. Rank, therefore, represents an average, and since most coals consist predominantly of humic material, the rank of the anthraxylon composing the vitrain and clarain present in the coal bed very largely determines the rank of common banded coal.

Chemical studies of the components of coal, the banded ingredients and the botanical entities (phyterals), using the methods of the ultimate and proximate analysis, although not neglected have not been adequate for providing a basis for sound judgment in regard to differences among the components. In general but slight differences have been discovered between bands of very bright coal, that is either vitrain or bright, highly anthraxylous clarain, and the duller portions of the coal consisting of grayish clarain and durain (8). Fusain may be definitely differentiated from the other banded ingredients in bituminous coals by its high carbon or fixed carbon content.

In comparing analyses of banded ingredients uncertainty usually exists concerning the degree of discrimination used in the selection of samples for analysis. This is particularly true when analyses are selected from a wide variety of sources representing samples collected by many persons in widely separated times and places. It still remains to be determined whether or not even the proximate and ultimate forms of analysis might not reveal consistent and significant differences between varieties of coal selected to represent actual differences in the botanical or phyteral composition. This is a desirable field of investigation.

With respect to the phyterals—differences are discoverable between humic and waxy phyterals, that is, between vitrain or anthraxylon and waxy spore

exines (10, p. 417), but it is suspected that such differences tend to disappear in coals of high rank (9).

In general, however, except for fusain in the middle and low rank varieties of coal, it may be that the data provided by ultimate and proximate analyses, and particularly by the latter, are not sufficiently specific in regard to chemical composition to permit differentiation of the various banded ingredients and of the phyterals found in coal (3, pp. 383–4).

Organic Analysis.—The conventional methods of organic analysis have also been applied to coal to a rather limited extent. The usual procedure of analysis involves investigation of samples collected by standard methods of face sampling. Hence the sample, when the common banded type of coal is used, represents an average of a variety of organically different substances or phyterals. Therefore the material analyzed is chemically complex, not only because of the complexity of the composition of the individual phyteral, but because a considerable number of such units are inextricably intermingled almost as in a liquid solution. Since most banded coal is predominantly humic in origin, the prevailing results will be very similar whatever coals were used, except for differences that might spring from variations in rank. It is not to be expected that the coal petrographer and coal botanist will be entirely satisfied with results obtained from analyses of such samples.

Such analytical examination as has been made of the banded ingredients and to a much less extent of the individual plant components or phyterals indicates that the organic substances that survive the diagenetic processes and form coal consist of aromatic compounds (4). This appears to be true whether the coal is composed of humic substances (anthraxylon or vitrain), waxy phyterals (spore, exines, cuticles, etc.) or fusain. Fusain displays distinctive characteristics that makes chemical differentiation possible, at least in the middle and low rank coals. Yet these differences are small and it is pointed out that they are none other than those indicated by elementary analysis (3).

In general it appears that the organic chemists regard physical variations in coal resulting from difference in phyteral composition as not necessarily chemically significant. "Differences in appearance of the bands of any given coal are not adequate criteria for differences in chemical composition. Although these differences in appearance may be associated with differences in chemical composition, both the amount and the direction of the differences must be determined by chemical means in each case" (3, p. 384).

In line with the conventional methods of analysis of organic compounds, the composition of coal has been investigated by halogenation, oxidation, reduction (hydrogenation), and by hydrolytic reactions, in general, using gross samples of coal rather than specific ingredients or phyterals.

The various methods of analysis lead to the same general conclusions in regard to the aromatic nature of the coal material. Differences in these compounds appear to parallel progressive change in coal from rank to rank. It does not yet appear that rank can be definitely identified by the state of condensation of the aromatic molecule, although it seems to a geologist that this possibility exists. Nor does it seem to be certain whether the overwhelming

predominance of the aromatic compound in coal is a result of the incoalation and coalification processes, or simply an inheritance of pre-coal conditions of the plant débris.

In closing this section it may be pointed out that the main efforts of coal chemists have been directed not toward discovering the fundamental chemical differences in the materials composing the "coal conglomerate," but rather toward the determination of the nature of substances derived from coal when it is subjected to thermal decomposition. It seems quite possible that the almost unlimited variety of materials present, at least potentially, in the liquid by-products of coke manufacture is partly responsible for the idea that the coal material itself is equally complex and varied, whereas complexity and variety in the by-products may be the result of the highly complex physical conditions accompanying heat treatment.

It is desirable to know more accurately the character of the initial source of these by-products and the extent to which the final complexity is the result of either initial complexity or physical heterogeneity. Such knowledge might also provide an answer to the unsolved problem of the cause of the coking phenomenon.

FUNDAMENTAL GEOLOGICAL RESEARCH INTO COAL CONSTITUTION.

The position of geology as an applied science has been so frequently and emphatically reiterated that it has come to be an accepted belief that for fundamentals the geologist must turn to the biologist, chemist, physicist, or mathematician for the correct solution of even geological problems, and that geology possesses no fundamental concepts in its own right. Even among geologists there is a common idea that fundamental research in coal must be carried on in the fields of botany, chemistry, or physics, irrespective of geological considerations. Such a conclusion reveals a failure to understand the importance of the coordinating and correlating function of geology.

May not research in coal in the biological and chemical fields in general have failed to reach the desired objective of an understanding of the nature and constitution of coal largely because basic geological factors have been neglected? Geological considerations would seem to be of fundamental importance in any basic research in coal material because coal is a product of geological process of a fairly definite general character.

Among these geological processes are certain important ones which experience, based upon wide investigation and careful observation of natural phenomena and intelligent deductions, has associated with the metamorphic process. Metamorphism is a basic geological concept; the process is described, defined, and identified by geological criteria. It is doubtful whether the general concept of metamorphism can be adequately defined in strictly chemical or physical terms, although explanation of the process can be made only in terms of physics and chemistry employed as the tools of geology.

The existence and patterns of numerous other geological phenomena have also been established by the geological methods of naturalistic interpretation of the physical environment and events. Explanations are rightly sought

through use of biological, chemical, and physical sciences and mathematics, but geologists should regard basic research in the fundamental nature of coal material as concerned primarily with a natural substance owing its existence and specific character to geological conditions. These conditions by reason of their progressive increase in severity produce coal from pre-coal material and subsequently alter coal through successive stages of increasing rank and ultimately change it to graphite. Geological processes bring about the chemical changes of coal formation and coal metamorphism and geologists should seek to determine both the nature of the geological influences that operate to change the organic materials and the reason for the specific changes produced.

Studies in coal resources and other studies relating to the physical and chemical constitution of coal such as have been suggested are essential preliminaries to fundamental coal research. Much more work along these lines needs to be done. Likewise the botanists have probed very closely to those vital considerations of basic research and the knowledge thus gained will contribute to the ultimate understanding of the fundamental constitution of coal. Such work needs to be continued.

The conclusions reached by the organic chemist, through conventional analytical procedure, tend to focus attention upon the failure of such investigations to discover chemical reality in physical differences recognized by the coal petrographer and coal botanist. The geologist should not, however, be satisfied with such conclusions unless they are based upon coal samples selected by specially trained coal geologists to illustrate specific varieties of coal material. Furthermore, the relation of chemical variations in coal material should be related more specifically to the kind and degree of geological forces that produce rank variations in different kinds of coal material. In general a more substantial and easily traveled bridge must be laid between geological and chemical concepts relating to coal before complete correlation of ideas is possible. It is important that the geologists on their part explain more clearly the nature of the geological factors that have been involved in the formation and metamorphism of coal and that the chemists understand the nature and importance of geological processes in bringing about these changes, in other words to regard coal as a dynamic substance.

CONCLUSION.

A basis exists for more systematic education and training in the field of coal geology. Coal geology elucidated by suitably trained personnel provides a discipline as rigorous as that provided by other but more conventional fields of academic study and research. It has the superior value of being directly concerned with a material of prime importance in our industrial civilization, and one whose importance increases as petroleum supplies decline. Special attention is called to the need for basic research in coal, thereby providing a foundation for general academic activities in this field. Without such basic research no substantial achievement in the academic field of coal geology can be expected. It would appear, therefore, that any educational institution

contemplating the establishment of courses in coal geology should support such plans by setting up a well organized program of basic research in coal.

Basic geological research in coal should explore the nature of the coal material as a substance fundamentally geological both in its origin and subsequent history. Although differences among coals can be described to a certain extent in physical terms, it is generally true that unless differences can be described in chemical terms their actuality is open to serious doubt. In order to achieve significant results the geological research, although carried on from a geological point of view, must seek for expression of the geological processes and materials in chemical terms. Undoubtedly this will require close cooperation between geologists and chemists, and the availability of chemists with an understanding and appreciation of geological philosophy.

It would be very unfortunate indeed if the suggestions that have been made should be interpreted as indicating that the geological approach provides a short cut to an understanding of the chemical constitution of coal and a bypassing of the methods of analytical chemistry. The significant aspect of the proposal is that the chemical investigations should be carried on in such a way that the geological factors that produced the various types and ranks of coal become a part of the chemical concepts. First, the nature of the geological factors will have to be determined, analyzed, and evaluated as to their probable influence on the chemical structure of coal. Whether or not this naturalistic geological approach to the problem can contribute any assistance to the solution of the central problem of the constitution of coal remains to be determined, but it seems probable that a well-trained capable geologist with adequate assistance in three or four years of undivided attention to the problem would be able to discover and define the main geological factors involved in the formation and metamorphism and geochemistry of coal. An entirely new approach to the study of the fundamental constitution of coal might result.

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Sept. 24, 1948.

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VARIATIONS IN GARNIERITE FROM THE NICKEL DEPOSIT NEAR RIDDLE, OREGON.[1]

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ABSTRACT.

Garnierite from near Riddle, Oreg., is an inhomogeneous material that has three general modes of occurrence. An orderly variation in the physical properties and chemical composition of eight analyzed specimens is a significant field guide for economic geologists examining nickel-silicate deposits. The NiO content of the specimens ranges from 2.6 to 37.0 percent. In general, the garnierite specimens rich in nickel are darker green than those poor in nickel and have a higher specific gravity, higher mean index of refraction, and different X-ray and differential thermal analysis patterns. Laboratory evidence supports the conclusion that the eight specimens are not variations of a single mineral but are mixtures of two or more hydrosilicates.

INTRODUCTION AND ACKNOWLEDGMENTS.

THE importance of nickel-silicate deposits as a potential source of nickel has in recent years prompted detailed studies of a number of such deposits in the Western Hemisphere. In each of these deposits the nickel is distributed in different kinds of material, but principally in a greenish, claylike substance widely known as "garnierite." In this paper, the term garnierite is used only as a general term to identify the greenish nickel-bearing material and not in any specific mineralogical sense. This usage is common practice among geologists in several countries.

The purpose of this paper is to record some data concerning eight specimens of garnierite selected from a large suite collected in 1940 from the nickel deposit near Riddle, Oreg., by W. T. Pecora and S. W. Hobbs. These specimens, labeled *A* to *H*, are significant because of their variations and para-

[1] Published with permission of the Director, U. S. Geological Survey.

genetic relations. No attempt is made to interpret the results of the field and laboratory studies of these specimens except in a general way.

Additional studies of garnierite are in progress in the laboratory of the Section of Geochemistry and Petrology, U. S. Geological Survey, with the hope that the mineralogy of garnierite and its relationship to hydrosilicates of similar character may be determined with more certainty. The writers gratefully acknowledge the professional aid of a number of their colleagues in the Geological Survey who have contributed to this investigation, all of whom, however, are not necessarily in accord with the conclusions set forth in this paper.

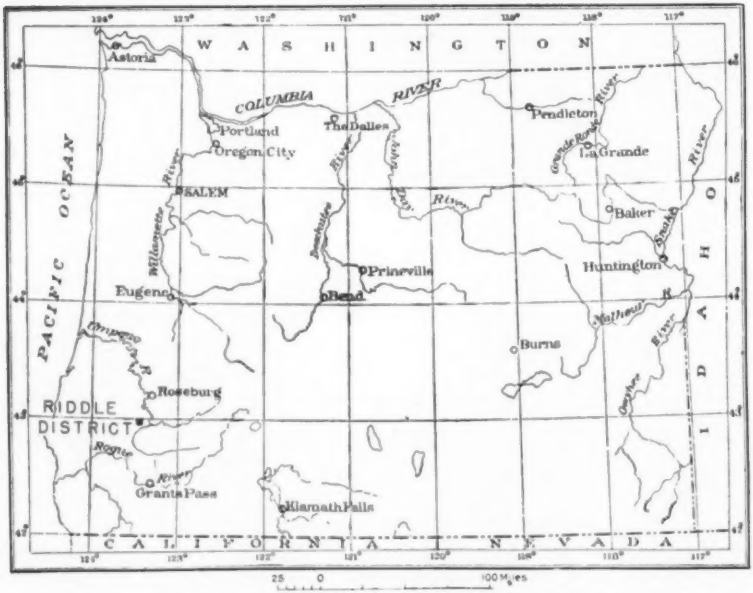

FIG. 1. Index map showing the location of the Riddle District in southwestern Oregon.

LOCATION AND GEOLOGIC SETTING.

The nickel deposit near Riddle, Douglas County, Oreg., is about 230 miles south of Portland, on the upper, southeastern slopes of Nickel (Piney) Mountain above an elevation of 2,000 feet. Most of the deposit is in sec. 17, T. 30 S., R. 6 W. (Fig. 1 and Fig. 2).

The geology has been described by several writers including Austin (2),[2] Von Foullon (16), Kay (8), Diller and Kay (6), and most recently by

[2] Numbers in parentheses refer to bibliography at end of paper.

Pecora and Hobbs (11). The deposit is essentially an irregular mantle of weathered peridotite resting on fresh peridotite (varieties saxonite and dunite). Although more extensive in the geologic past, the nickel deposit at the present time comprises an "upper" and a "lower" deposit on gentle slopes separated by a steep slope underlain by fresh peridotite. In the lower deposits garnierite is known to extend to depths of 50 to 75 feet. In the upper deposit depths between 100 and 200 feet are not improbable. In the formation of the garnierite dunite has been more susceptible to the long-continued weathering than saxonite.

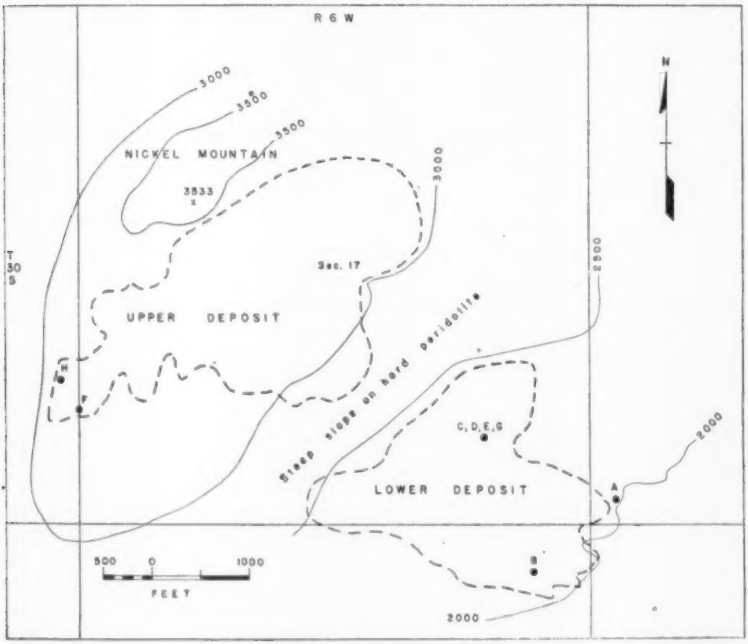

FIG. 2. Sketch map of the nickel-silicate deposit near Riddle, Oreg. (modified after Pecora and Hobbs, 1942, pl. 38) showing the location of the analyzed specimens.

FIELD RELATIONS.

The location of the garnierite specimens *A* to *H* is indicated in Figure 2 and their general nature and field relations are described in Table 1. These specimens represent the principal varieties of garnierite encountered in the nickel deposit.

Light-colored material (specimen *A*) is not abundant and occurs only in those rare places where dunite partly weathered to clay is exposed. Yellowish-

TABLE 1.

GENERAL DESCRIPTION OF THE EIGHT ANALYZED GARNIERITE SPECIMENS FROM THE NICKEL DEPOSIT NEAR RIDDLE, OREG.

Garnierite specimens	Location (see Fig. 2)	Occurrence	Ridgway color and color formula	Specific[1] gravity (±0.01)	Mean index of refraction (±0.001)
A	Roadcut 1,500 feet S.E. of shaft in the lower deposit.	Light-colored quartz-free clay containing films of MnO and enclosing irregular fragments of weathered dunite.	Sea foam yellow YG-Y 25″-f	2.57	1.564
B	Trench 1,500 feet S.-S.E. of shaft in lower deposit.	Irregular, discontinuous garnierite-quartz veinlets in lighter-colored garnierite similar to specimen A.	Pale viridine yellow GG-Y 29-f	2.55	1.563
C	Collar of shaft in lower deposit.	Irregular, discontinuous garnierite-quartz veinlets cross-cutting veinlets similar to specimen *B*.	Light viridine green GY-G 33-f	2.58	1.565
D	Same as *C*.	Irregular garnierite-quartz veinlets cross-cutting veinlets containing specimen *D*.	Light lumière green GG-Y 29′-d	Not det.	1.567
E	Same as *C*.	Veinlike mass of quartz-garnierite cross-cutting veinlets containing specimens *C* and *D*.	Chrysoprase green GB-G 37-b	2.67	1.575
F	Collar of west shaft in the upper deposit.	Veinlike mass of quartz-garnierite traversing veinlets with garnierite similar to specimens *A* and *B*.	Cobalt green GB-B 37′-b	2.69	1.575
G	Same as *C*.	Irregular mamillary crusts on wall of vug along wet fissure traversing veinlets containing specimens *C*, *D*, *E*.	Light cendre green GY-G 33′-d	2.92	1.592
H	West face of open cut 400 feet N.-N.W. of west shaft in the upper deposit.	Thin veinlet in porous limonitized dunite. Traverses veinlet containing garnierite similar to specimen *F*.	Tiber green G 35-d	2.98	1.601

[1] Pycnometer method; water immersion.

green or greenish-yellow material like specimens *B* to *D* is most abundant in the lower deposit and on the steep slope between the lower and upper deposits in isolated areas of weathered dunite surrounded by partly weathered saxonite. Specimens *E* and *F* represent varieties of bluish-green garnierite that are commonly associated with quartz (and some chalcedony) in an intricate boxwork traversing lighter-colored garnierite; porous brownish-colored, weathered peridotite; or loose, yellowish-brown, limonitic material presumably derived by complete weathering of peridotite. Dark-green material like specimens *G* and *H* is rare and was observed only along wet, sheared, and slicken-sided surfaces and on the wet walls of vugs.

Irregular black films of manganese oxide characterize the light-colored, quartz-free claylike material (specimen *A*) but are absent in the darker-colored varieties of garnierite. Irregular fragments of weathered peridotite, particularly dunite, imbedded in this quartz-free clay are cut by and commonly separated from the clay itself by thin black films of manganese oxide. Thin seams of quartz-free clay along well-formed joint cracks in partly weathered peridotite are bordered by the same kind of black films.

The proportion of garnierite and quartz (and chalcedony) in the simple and intricate quartz-garnierite veinlets and boxwork shows a significant relationship to paragenesis. In the simple veinlets from which specimens *B* to *D* were obtained, quartz is subordinate and occurs as a paper-thin, porce-

laneous, discontinuous lattice work in the garnierite. In the complex quartz-garnierite boxwork, bluish-green garnierite is commonly subordinate to the quartz and occurs as isolated masses in chambers enclosed by septa of quartz that is commonly brown-stained. A greater abundance of boxwork quartz is banded and occurs near the surface of the nickel deposits.

Dark-green garnierite like specimens *G* and *H* is most common on the walls of permeable fissures several feet below the present surface. Wet walls of vugs along some fissures that traverse a quartz-garnierite boxwork are studded with this kind of garnierite; and many occurrences in shafts and adits range from 10 to 40 feet below the surface. On the western slope of Nickel Mountain, along the walls of adits that cut surface rubble and landslide material, dark-green garnierite similar to specimen *G* has been deposited in voids occurring in fragmental, quartz-rich, water-soaked slope material.

ORIGIN AND SIGNIFICANCE.

On the basis of field relations, three different processes in the formation of garnierite near Riddle are postulated:

(1) Light-colored, nickel-poor garnierite like specimen *A* is a direct, clay-like alteration of olivine-rich rock.

(2) Light-green and bright-green garnierite like specimens *B* to *F* is a result of a continual chemical reaction of ground water on earlier-formed garnierite. In this process manganese oxide is completely leached; magnesium, nickel, and iron are partly leached; and some silica is deposited as residual quartz. Newly formed garnierite is continually reconstituted in place at the expense of earlier-formed garnierite.

(3) Dark-green garnierite (richest in nickel) like specimens *G* and *H* has been deposited from ground-water solutions containing magnesium, nickel, and silica derived from material subjected to the leaching process of (2).

If the direct alteration of rock to clay (1, above) is active in the Riddle deposit at the present time, it is insignificant with respect to the other two processes. Pecora and Hobbs (11) proposed that the initial rock alteration was a superficial one, and that it occurred under physiographic conditions prevalent prior to the Pleistocene, perhaps concurrently with the formation of the Klamath erosion surface in Miocene time. The uplift and dissection of that surface have led to the reworking of that original material by surface waters and has resulted in the thinning of the vertical section of the nickel-bearing mantle by mechanical and chemical action as well as in the formation of local, high-grade pockets by enrichment. The dominant process at the present time is one of leaching of magnesium and nickel from already formed garnierite and deposition of free silica at and near the surface.

DESCRIPTIVE MINERALOGY.

General Statement.—The eight specimens selected for study represent a suite of inhomogeneous material. An orderly variation, however, has been

recognized in color, mean index of refraction, specific gravity and nickel-magnesium content. This variation is a reflection of the modes of occurrence of the garnierite. Other laboratory studies support the conclusion that the orderly variation has been the result not of the formation of an isomorphous mineral series, as might be supposed, but rather of mixtures of different hydrosilicates.

Physical Properties.—All of the air-dried specimens are brittle. In the wet state the nickel-poor specimens are plastic to semiplastic and the nickel-rich specimens are nonplastic. Specimen *F*, for example, has remained nonplastic although immersed in a bottle of water since 1940. The color of each specimen is distinct and each specimen appears to be homogeneous to the eye.

Specific gravity (pycnometer method) of the eight powdered specimens ranges from 2.55 to 2.98. As shown in Table 1 and Figure 3, the nickel-rich specimens have the higher specific gravities.

TABLE 2.

CHEMICAL ANALYSES OF EIGHT SELECTED SPECIMENS OF GARNIERITE FROM THE NICKEL DEPOSIT NEAR RIDDLE, OREG.
(K. J. Murata, analyst.)

	A	*B*	*C*	*D*	*E*	*F*	*G*	*H*
SiO_2	42.01	46.48	47.09	45.6	42.68	44.39	44.27	42.18
Al_2O_3	0.28	0.16	none	none	none	none	none	none
Fe_2O_3	3.39	3.54	2.81	2.2	0.22	0.06	0.62	1.51
FeO	0.72	—	—	—	—	—	0.13	—
NiO	2.62	5.42	8.52	9.0	20.44	24.22	33.05	37.08
MgO	36.36	29.79	25.94	27.7	18.79	15.62	8.99	5.28
CaO	0.24	none	0.50	none	0.27	0.16	0.16	0.13
H_2O^-	1.58	4.62	5.40	5.3	6.82	6.45	4.58	5.32
H_2O^+	13.28	10.76	10.09	11.0	10.30	9.04	8.39	8.16
Totals	100.48	100.77	100.35	100.8	99.52	99.94	100.19	99.66
Mol. ratio								
RO	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00
SiO_2	2.21	2.86	3.07	2.82	2.87	3.15	3.30	3.35
H_2O^+	2.32	2.21	2.19	2.27	2.31	2.14	2.08	2.16

Precise optical constants of the specimens have not been determined because of the cryptocrystalline and fibrous nature of the material. Under crossed nicols, specimen *A* is a mixture of grains that are massive and essentially isotropic or only vaguely fibrous and perceptibly anisotropic. The other specimens are anisotropic and fibrous. The arrangement of the fibers is random, radial, or subparallel. In general, the lighter-colored (nickel-poor specimens have a lower birefringence (0.003 to 0.009, estimated) than the darker-green varieties (0.010 to 0.020, estimated) and their fibrous aggregates are essentially unoriented.

The approximate mean index of refraction of the fibrous aggregates ranges from 1.563 to 1.601, and the nickel-rich specimens have the higher indices (Table 1 and Fig. 3). An approximate mean index of refraction of each

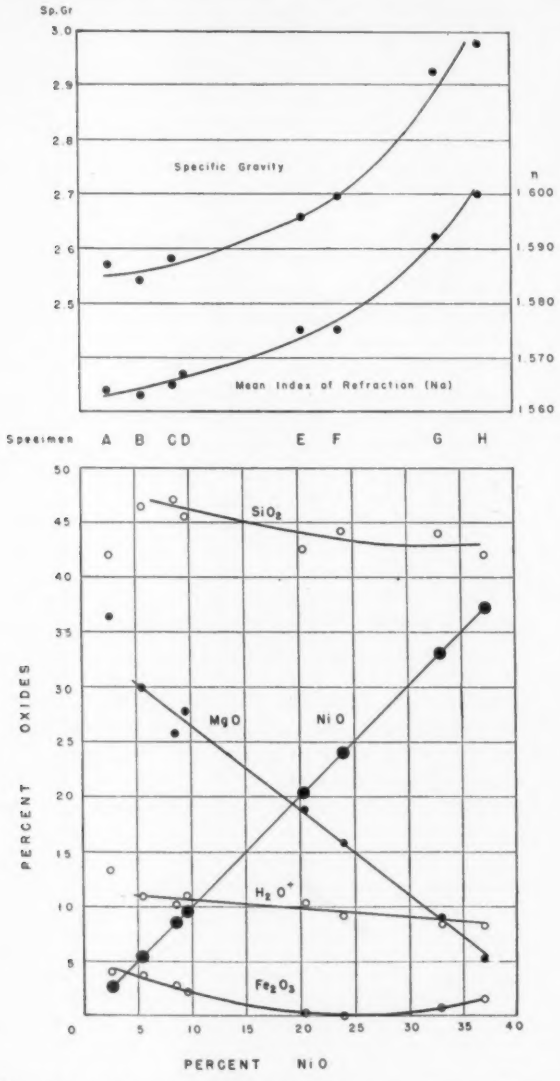

FIG. 3. Variation diagram for the eight analyzed specimens of garnierite from the Riddle nickel district.

specimen has been calculated according to the Law of Gladstone and Dale (9a) as expressed in the formula:

$$n = 1 + dk, \text{ where}$$

n equals the mean index of refraction
d equals the specific gravity of the specimen
k equals the sum of the specific refractive energies of the component oxides from the chemical analysis.

The calculated indices are consistently higher than the measured ones by 0.02 to 0.03.

Chemical Composition.—Chemical analyses of specimens *A* to *H* are given in Table 2. The most striking feature brought out by the analyses is the progressive increase of NiO with the decrease in MgO, readily shown in the variation diagram (Fig. 3). The ratio of SiO_2:RO for all the specimens ranges from that of serpentine (2:3) to that of saponite (4:3). A simple formula, however, cannot be calculated from any of the analyses. The quantity of free silica present in the specimens as admixed grains of submicroscopic size is believed to be negligible. From the evidence of chemical analyses alone there is reason to believe that the specimens *A* to *H* do not represent variations of a single mineral or variations between two end members of an isomorphous mineral series. The analyses can be most simply interpreted as mixtures of serpentine and saponite.

Water is lost at an irregular rate as shown by the dehydration curve in Figure 4. According to P. G. Nutting (personal communication) the curve resembles, but is not identical to, those established for serpentine in earlier experiments.

X-ray Diffraction and Differential Thermal Analysis Patterns.—X-ray powder diffraction photographs of the analyzed specimens were made by J. M. Axelrod and differential thermal analysis patterns of the same material were made by G. T. Faust in the laboratory of the Section of Geochemistry and Petrology, Geological Survey. Their joint conclusions are summarized below:

	X-ray patterns (J. M. Axelrod)	Differential thermal analysis patterns (G. T. Faust)
Specimens *A*, *B*	Resemble serpentine patterns and are distinct from patterns of *C* to *H*.	Resemble joint patterns of chrysotile and deweylite.
Specimens *C*, *D*, *E*, *F*	Resemble mixed serpentine and deweylite patterns.	Resemble joint patterns of chrysotile and deweylite.
Specimens *G*, *H*	Resemble mixtures of serpentine, deweylite, and pimelite patterns.	Resemble joint patterns of saponite (pimelite) and either or both chrysotile and deweylite.

FIG.

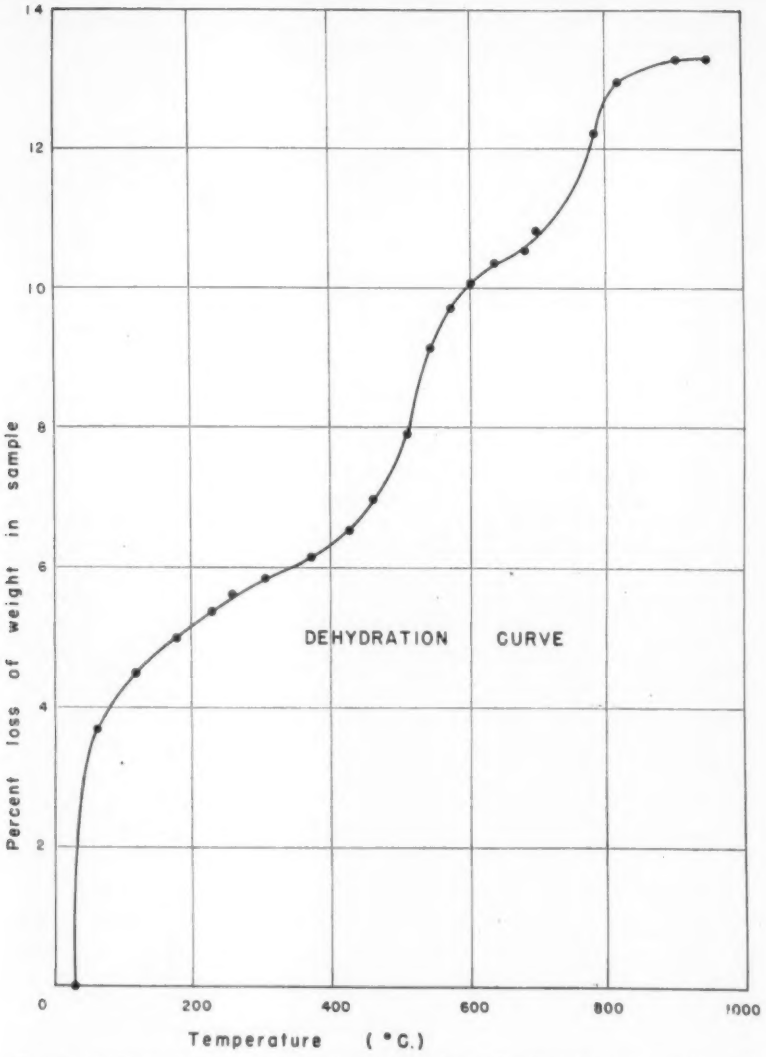

FIG. 4. Dehydration curve of garnierite (Specimen *F*) plotted from experimental data of P. G. Nutting.

The conclusions of Axelrod and Faust support other evidence from optical studies and chemical analyses that the specimens are not representative of a single, pure mineral.

HISTORY OF NOMENCLATURE.

During the past century a number of specific mineralogical names have been introduced into the geological literature in reference to the green, nickel-bearing hydrosilicate now generally called garnierite. These names include nickel-gymnite, genthite, noumeite, garnierite, nepouite, revsdinskite, maufite, pimelite, and deweylite.

The green, nickel-bearing hydrosilicate from Lancaster County, Pa., named *nickel gymnite* by Genth (7), was renamed *genthite* by Dana (5). Genthite has been used to designate the specific nickel-bearing mineral at Riddle, Oreg., and Webster, N. C., by a number of writers including Clarke (4) and Kay (8), Diller and Kay (6), and Ross et al (13). This material is the same as that called garnierite in this paper.

Liversidge (9b) assigned the name *noumeite* to a green nickel-bearing hydrosilicate from New Caledonia. As a result of a communication from Jules Garnier pointing out the similarity of the new mineral to material described earlier by Garnier (6a), Liversidge (9c) renamed as *garnierite* the mineral he had earlier described as *nomeite* and assigned the name *noumeite* to a second mineral from the same general locality. Caillère (3), Selfridge (14), Alexeeva and Godlevsky (1), and Spangenberg (15) investigated several nickel-bearing hydrosilicates and concluded that material called garnierite, noumeite, nepouite, and revsdinskite are not specific minerals, are closely related if not identical, and are mixtures of different hydrosilicates.

De Moraes et al (10) use "garnierita" in reference to the green, nickel-bearing hydrosilicate in several nickel-silicate deposits in Brazil. Pecora (12) uses the terms garnierite and garnieritized rock in the same sense. Lacroix (9) likewise uses garnierite as a general term for the green nickle ore in New Caledonia and he reserves the names noumeite and nepouite as specific mineral names.

It is apparent, therefore, that the identity of garnierite from other localities has not been established with any certainty, and that material called garnierite by earlier writers is a mixture of different hydrosilicates.

CONCLUSIONS.

Garnierite in the nickel-silicate deposit near Riddle, Oreg., is a nickel-bearing hydrosilicate that has three modes of occurrence that reflect an orderly variation in color, specific gravity, mean index of refraction, and nickel content. These relations can serve as a useful field guide to economic geologists. Evidence from laboratory study made on eight analyzed specimens supports the conclusion that garnierite near Riddle is not a single mineral but a mixture of at least two and possibly three hydrosilicates analogous in structure to serpentine, deweylite, and saponite (pimelite). In the light of data brought out by these studies the name garnierite is on par with other such "mineral-

mixture" names as limonite, bauxite, and "manganese wad." Retention of the name garnierite as a general field term serves a very useful purpose among economic geologists. This usage is common among geologists of many countries.

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STRUCTURAL CONTROL AND MINERALIZATION AT THE SEVENTY NINE MINE, GILA COUNTY, ARIZONA,

GEORGE A. KIERSCH.

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ABSTRACT.

The Seventy Nine mine is in the Dripping Spring Mountains near Hayden, Arizona. The Paleozoic section, consisting of limestones, shales, and quartzite, has been faulted, sheared, and invaded by a granitic dike system.

Cretaceous-Tertiary faulting is prominent and of at least three distinct periods. Initial major north-south normal faulting resulted in the formation of essentially east-west shear zones which were invaded by apophyses of the Central Arizona batholith to form the dike system. Postdike recurrence of the normal faulting produced a shearing of the dikes and shattering of favorable horizons in the adjacent Naco limestone. Invading ore solutions penetrating upward along the major faults and shear zones deposited their ores within the shattered North dike and favorable beds of impure Naco limestone. Post-ore faulting has displaced some ore bodies.

Approximately $4,000,000 has been recovered between 1919 and 1947 in metals, lead being the most important. Early production consisted

of lead carbonate ore from bed replacement deposits. Since 1940 the major production has been from lead-zinc sulfide ore occurring as replacement veins in the North dike.

Hypogene mineralization was deposited in a definite but interrupted three-stage sequence. Early pyrite was shattered and invaded by sphalerite, "argentiferous" galena, and chalcopyrite. Later quartz cuts all earlier sulfides. The bed replacement and upper parts of the North dike vein replacement ore bodies have been extensively altered by oxidation and supergene enrichment. The iron, zinc, and copper content was subtracted, with most galena being altered to cerussite.

The ore deposits fall within the mesothermal temperature range.

INTRODUCTION.

THE Seventy Nine mine is seven and one-half miles by road north of the town of Hayden in the Banner mining district, Gila County, Arizona.

Originally restricted to oxidized lead ore production, recent operations have developed considerable lead-zinc sulfide tonnage. The structure and occurrence of this hypogene ore in close association with a granitic dike system may prove of interest.

Some of the earliest geologic work to include the Seventy Nine mine area was that of F. L. Ransome[1] in 1910–11. One of the earliest descriptions of the mine is given by C. P. Ross.[2] J. B. Tenney in 1941–42 made a private examination and report on the property which was not accessible to the writer. N. P. Peterson,[3] U. S. Geological Survey, in 1943 while working on the geology of the Christmas mine area, measured the geologic section so well exposed due north of Tornado Peak (Fig. 2). The Seventy Nine mine is within and near the southern boundary of the U. S. Geological Survey's Ray topographic sheet published in 1910.

The author made a study of the Seventy Nine mine and adjacent area during 1946–47 in conjunction with the operating company. Much of this investigation was embodied in a thesis[4] submitted to the University of Arizona. The following presents a part of the findings of that field and laboratory investigation.

Appreciative thanks are due the officials of the Shattuck-Denn Mining Corporation and Mr. John E. McKay, superintendent of the Seventy Nine mine, for their help and cooperation during the field work and their permission to publish this paper; Mr. H. O. Woods, formerly superintendent of the Hayden smelter, for living accommodations and equipment; Drs. B. S. Butler and M. N. Short, of the University of Arizona, and Dr. E. D. Wilson, Arizona Bureau of Mines, for their guidance, many suggestions, and valuable criticisms of the manuscript.

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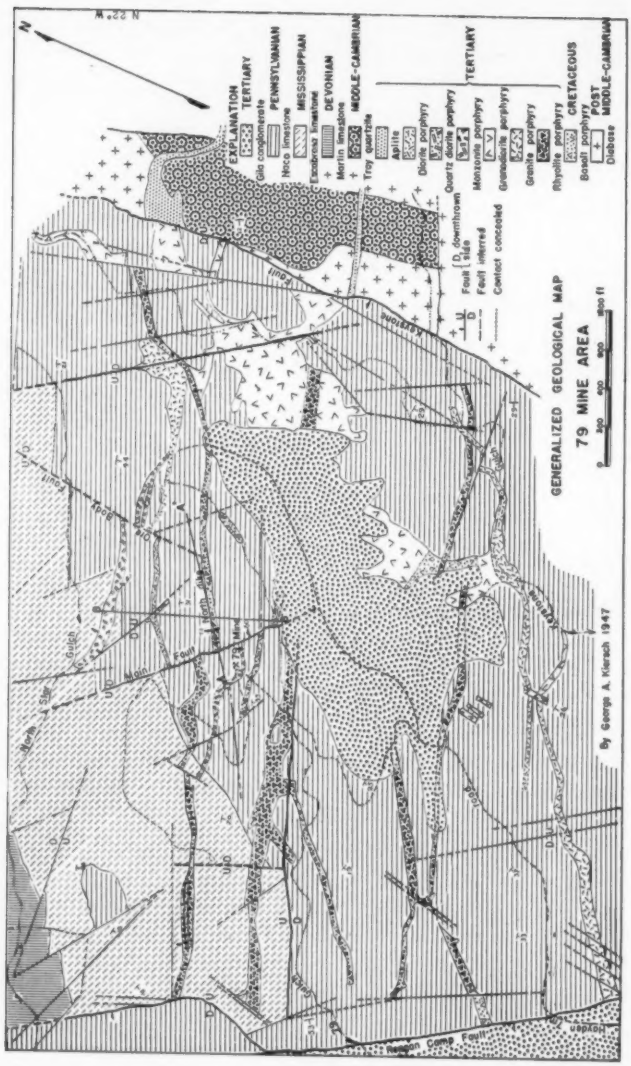

FIG. 1. Generalized geological map 79 mine area.

GEOMORPHOLOGY.

The Seventy Nine mine area as here considered consists of two subdivisions, a western and a central belt within the Dripping Spring Mountains separated by the northward-trending Keystone fault (Fig. 2).

The western belt consists largely of highly faulted and sheared steeply southward-dipping Paleozoic sediments, intruded by a system of porphyry dikes. This belt, which is bordered on the west by the Reagan Camp fault, ranges in altitude from about 2,800 to 4,200 feet.

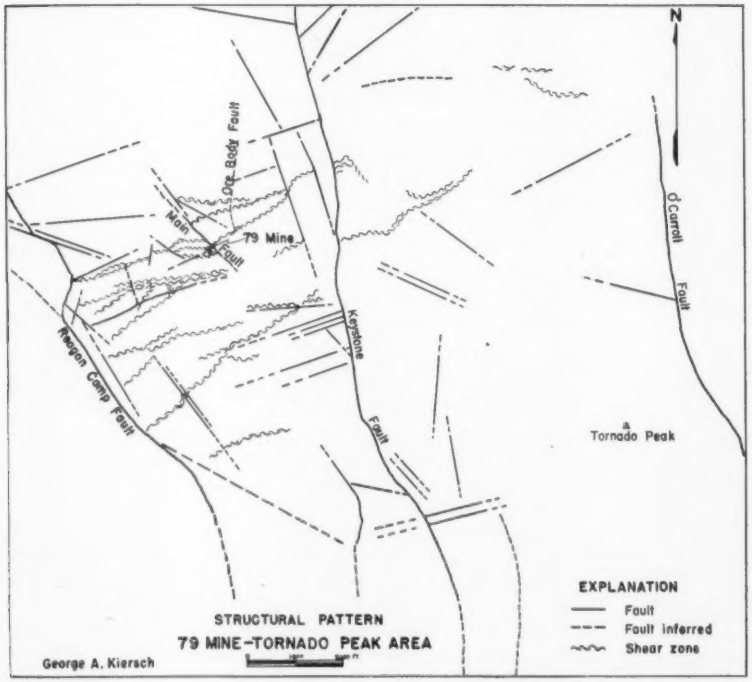

FIG. 2. Structural pattern (shear zones occupied by granitic dikes).

The central belt embraces the gently dipping strata of the main Dripping Spring Mountains and ranges in altitude from about 3,000 to 4,500 feet. Gently southward-dipping Paleozoic sediments underlain by an intrusive diabase are cut by minor scattered bodies of porphyritic rocks. The central belt extends eastward from the Keystone fault.

A fault system striking about N 70° E has produced a decided drainage pattern in both physiographic belts.

Sedimentary Rocks.

The strata in the Seventy Nine mine area range from Precambrian to Tertiary in age and are of the same names as used throughout much of central Arizona.

The oldest rock exposed is the Precambrian Mescal limestone of the Apache group. It rests upon intrusive diabase and crops out to a maximum thickness of 140 feet. Above the Mescal are the Middle Cambrian Troy quartzite, thin to thick cross-bedded, pebbly beds approximately 400 feet thick, succeeded by 225 feet of undifferentiated shale and quartzite probably Middle Cambrian; Upper Devonian Martin limestone, consisting of thin beds with some shale 250 to 328 feet thick; Lower Mississippian Escabrosa limestone, a massive cliff-former 440 to 581 feet thick; and Lower Pennsylvanian Naco limestone, thin beds with abundant chert from 385 to 1,000 (+) feet thick. This entire section appears to be conformable, although separated by at least three disconformities.

Isolated erosional remnants of the Gila conglomerate, parts of which are of Pliocene age,[5] crop out within the area. They also occur as extensive valley fill material to the west of Reagan Camp fault (Fig. 1). The Gila conglomerate consists of fragments of the local igneous and sedimentary rocks poorly sorted in a sandy and limy cement. South of the Seventy Nine mine it includes typical mineralized material.

Igneous Rocks.

Intruded as a sill into the Mescal limestone and as small stringers and irregular apophyses cutting the Troy quartzite is the widespread central Arizona diabase. It crops out immediately east of Keystone fault, where the large fault displacement has exposed the lower part of the stratigraphic section. M.N. Short and others[6] have determined the diabase to be post-Middle-Cambrian and pre-Upper Devonian in age from contact relationships with the Troy quartzite, south of Superior.

Basalt porphyry is present as an intrusive body (sill?) cutting the Naco limestone. Ross[7] has described extensive Upper Cretaceous basaltic outpourings and intrusive bodies occurring as dikes and sills in the adjoining area to the east and south. The Seventy Nine mine area basalt porphyry is comparable to that described by Ross and is thus referred to an Upper Cretaceous age.

Presumably during the Cretaceous-Tertiary (Laramide) interval, this region was subjected to deformation, accompanied in its later stages by intrusion of acid igneous rocks in the form of dikes, sills, and plugs. Porphyritic bodies of rhyolite, granite, granodiorite, monzonite, quartz diorite, and diorite porphyries intruded the shear zones, especially between the Reagen Camp and

[5] Knechtel, M. M., Geologic relation of the Gila conglomerate in southeastern Arizona: Am. Jour. Sci., vol. 31, p. 86, 1936.

[6] Short, M. N. and others, Geology and ore deposits of the Superior mining area, Arizona: Arizona Bur. Mines Bull. 151, p. 35, 1943.

[7] Ross, C. P., Ore deposits of Saddle Mountain and Banner mining districts, Arizona: U. S. Geol. Survey Bull. 771, p. 19, 1925.

Keystone faults. East of Keystone fault several creamy colored aplite dikes together with minor porphyry dikes intrude the diabase and Troy quartzite.

The acid intrusives are probably apophyses of the deep-seated Central Arizona batholith so named by Ettlinger.[8] He has put the time of intrusion as post-Pennsylvanian (probably Laramide).

The relative times of intrusion of the dikes are obscure except for a few general features.

1. Rhyolite porphyry is cut by dikes of monzonite porphyry and granite porphyry.
2. Granodiorite porphyry cuts dikes of granite porphyry.

STRUCTURE.

Folding and Low Angle Faulting.

The Dripping Spring range has a general northwestward trend and is apparently bounded on both sides by faults of similar irregular strike. Cutting across the anticlinally uplifted Dripping Spring range block, large faults of a general north-south direction have dissected the mountains into several physiographic belts (Fig. 2).

The tilting which accompanied this crustal movement produced a comparatively even tilt of about 15° to the south for the pre-Tertiary strata of the Dripping Spring range throughout this area. Subsequent faulting has modified the original tilt of the beds; numerous fault blocks west of the Keystone fault have a dip of 30° to 40° to the south.

Bedding plane faulting is suggested by the gouge found between the thin-beds comprising the Discovery ore body (Fig. 4).

High Angle Faulting.

The high angle faults of the Seventy Nine mine are of pre-ore and post-ore ages. The earlier were important in localizing mineral deposition, the later in displacing ore bodies and influencing the topography.

Pre-ore.—The main pre-ore faults of a north to N 31° W strike consist of O'Carroll, Keystone, Ore Body, and Reagan Camp faults (Fig. 2). Associated with these faults are strong shear zones of a general N 60°–70° E strike.

Most of these major faults are of normal displacement and dip steeply west. The largest, Keystone fault, has a normal displacement of over 2,000 feet. As a result of this vertical movement, major shear zones were formed having a general N 60°–70° E strike (Fig. 2). The greatest number of shear zones was formed between the Keystone and Reagan Camp faults with fewer formed to the east toward O'Carroll fault. Field evidence shows a negligible to small amount of vertical movement along the shear zones.

Probably closely following the earliest pre-ore faulting, the granitic rocks from the parent Central Arizona batholith were emplaced. These acid

[8] Ettlinger, I. A., Ore deposits support hypothesis of a Central Arizona batholith: Am. Inst. Min. Met. Eng. Tech. Pub. 63, 1928.

magmas invaded the weak shear zones, and formed the numerous dikes, sills, and irregular granitic masses of the Seventy Nine mine area.

A second period of pre-ore faulting followed the emplacement of the dikes. This post-dike and pre-ore faulting consisted of a recurrence of movement along the major north-south faults. The resulting stresses fractured the numerous dikes of the area with a general shearing of N 70°–85° E and a tension fracture direction of about N 55° E.

At this time or slightly later, numerous faults having a near N 70° E strike were formed. These faults normally show vertical displacement of the beds; south block generally moving up with respect to the north block. They are invariably mineralized. A small part of this movement may be post-ore.

This second period of pre-ore faulting shattered and made permeable the dikes and adjacent favorable limestone beds. Ore solutions closely followed, possibly even before faulting ceased.

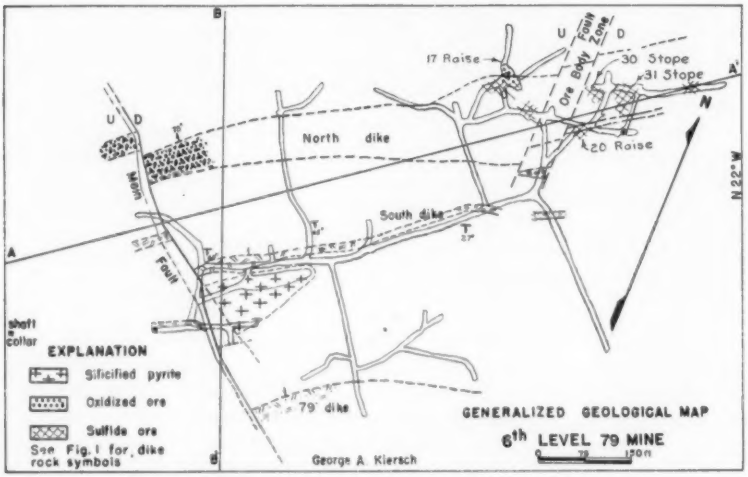

FIG. 3. Generalized geological map 6th level, 79 Mine (see Figs. 1 and 4 for areal position).

The pre-ore faulting is postulated as of Laramide (Late Cretaceous to Early Tertiary) age.

Post-ore.—The major post-ore faulting is represented by the Main fault and others having a general N 35°–45° W strike. Apparently associated with this period was some additional movement along the pre-ore N 70° E faults.

The Main fault, largest of the post-ore breaks, dips 60° eastward and has a nearly vertical normal displacement. This fault displaces the Discovery and Massive Pyrite ore bodies and the North dike. Several other faults having a similar strike displace the North dike, and are also thought to have a post-ore origin (see Fig. 1).

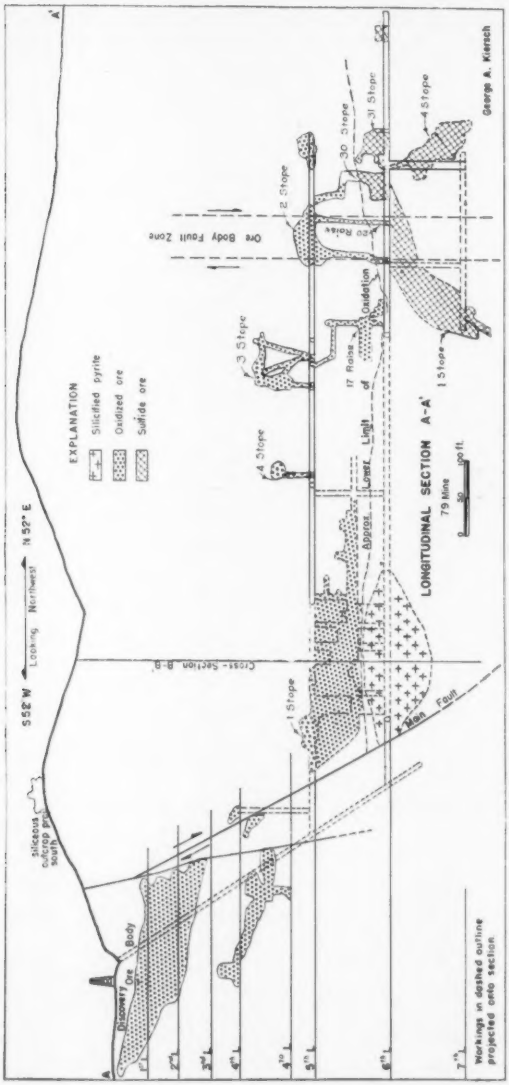

FIG. 4. Longitudinal section A–A', 79 Mine (see Fig. 1).

The main period of post-ore faulting was prior to the deposition of the Gila conglomerate. No displacement of that formation is apparent along the strike of the Main fault south of the Seventy Nine mine (see Fig. 1). The post-ore faulting is postulated to have occurred in Middle to Late Tertiary time.

Minor faulting during Quaternary (?) time with probably some tilting has occurred since deposition of the Gila conglomerate; evidenced by small faults found therein and a steep dip to some of these beds.

ORE DEPOSITS.

History and Production.

The Seventy Nine mine was named after its location year, 1879. The Continental Commission Company began initial operations in 1919 and produced at about a 50 tons per day capacity from the Discovery ore body. This production of lead carbonate ore was continuous except for the year 1921 (a depression year) until lengthy litigation closed the property in 1923.

In 1928 the Seventy Nine Lead-Copper Company was formed and produced at about previous capacity until shut down in 1938. Lead carbonate ore, containing some values in copper, silver, and gold, was mined principally from the Discovery and Massive Pyrite ore bodies (Fig. 4).

The Shattuck-Denn Mining Corporation, a previous part owner, assumed control in 1940 and began the present period of operation. Since its reopening most of the production, some 500 tons per month, has been lead-zinc sulfide ore. Mining has been from ore bodies associated with the North dike in the vicinity of the Ore Body fault.

Total production, to date, of the Seventy Nine mine has grossed about four million dollars.[9]

Types of Ore Deposits.

The ore bodies of the Seventy Nine mine are of the bed replacement and replacement vein types. The early mine production was from the former type; recent operations have produced from the latter type (Fig. 4).

Mineralization.

Discovery Ore Body.—Surrounded by a strong gossan, this body crops out just north of the collar of the inclined shaft. It is mineralized for 300 feet along the strike of the Naco limestone beds, in a series of two- to three-foot finely fractured and broken, thin calcareous shale beds separated by thin siliceous shale and siliceous strata. This mineralized and interbedded material, over 50 feet thick, dips 25°–35° to the south and apparently intersects the South dike (lower workings inaccessible to the writer). It is cut off by the post-ore Main fault on the east and fingers out in less shattered beds to the west.

[9] Wilcox, J. A., Personal communication, April 1947.

Mineralization has been selective in replacing fractured, thin calcareous shale. Preference for shaly material is the rule throughout the Seventy Nine mine area; nowhere was pure massive limestone replaced.

Massive Pyrite Ore Body.—Located immediately east of the Main fault this second largest single ore body within the Naco limestone is between the 5th and 6th levels (Fig. 4). On the 6th level, thin beds of shaly and calcareous material alternating with impure limestone have been replaced by massive pyrite, later silicified. The pyrite body extends south to the Seventy Nine dike and north to the South dike (Fig. 5). It is faulted to the west and fingers out in the thin beds within 200 feet to the east.

Up dip from the pyrite ore body between the South and North dikes (Fig. 5), mineralization extends for a distance of about 200 feet along the strike of the beds and for about 50 feet vertically. Fractured and shattered alternating thin-bedded, calcareous shale and impure limestone were selectively mineralized, being strongest near the South dike.

A large mass of iron stained silica 15 feet high crops out on the surface above this ore body with only slight surface indications of gossan.

Other Ore Bodies in Limestone.—In the vicinity of the Ore Body fault, Number 17 raise, 6th level, Naco limestone beds adjacent to the north contact of the North dike are mineralized. It roughly parallels the dike contact, nowhere extending a great distance from the porphyry.

At Number 20 raise, 6th level, strong mineralization with abundant silicification is present along the southern wall of the North dike, nowhere extending more than a few feet into the limestone beds.

Dike Ore Bodies.—Mining operations since 1940 have been largely restricted to discontinuous vein-replacement ore bodies associated with the North dike. These deposits are found along the north and south contacts as well as within the dike. In the vicinity of Number 17 raise, 6th level (Fig. 4), the rhyolite porphyry-limestone contact has been extensively shattered, altered, and mineralized along the north wall and within the dike from above the 5th to below the 7th level.

Discontinuous ore bodies are numerous within the porphyry as shown by Figure 4. These sulfide bodies are in extensively fractured rhyolite porphyry with an abundance of argillized [10] material associated as stringers throughout the mineralized sections. This argillized material is less common in those parts of the dike which separate the ore bodies, the expected distribution due to its apparent hydrothermal origin. Some pyrite is present in the sulfide ore stringers, but it is most prominent as massive bands bordering the highly fractured and mineralized parts of the porphyry.

The hypogene ore bodies, consisting of closely spaced sulfide stringers separated by argilliferous seams and altered porphyry, show varying degrees of silicification. The host rock, rhyolite porphyry, has had much sericitization of its feldspars.

[10] Lovering, T. S., The origin of the tungsten ores of Boulder County, Colorado: ECON. GEOL., vol. 36, p. 236, 1941. (Argillized formed from the root word argil, meaning a white clay, is here used to describe the effects of apparent hydrothermal alteration that has resulted in the prominent development of clay minerals.)

Most of the ore bodies associated with the porphyry on the 5th, 6th, and 7th levels are not connected vertically or horizontally. Mineralization is largely confined to an area in the North dike near the Ore Body fault (Fig. 3). This confinement of the ore bodies to a section of the dike laterally and vertically suggests the possibility that the dip of the mineralized fractures may have stopped solutions from moving vertically and forming continuous ore bodies.

Relation of Ore to Structure.

Pre-ore.—Faulting, together with the physical character of the wall rocks, has been the major controlling factor in localizing the ore-bearing solutions.

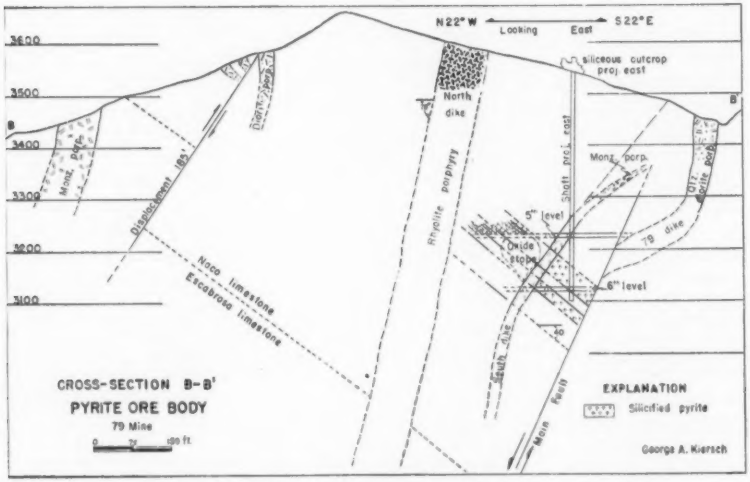

FIG. 5. Cross-section B–B′, pyrite ore body (see Fig. 1).

The initial faulting produced shear zones of a general N 60°–70° E strike. These zones were subsequently invaded by numerous granitic porphyry dikes and sills. The second period of pre-ore faulting consisted of renewed activity along the major north-south faults. This movement produced pronounced shearing and fracturing of the dikes. The North dike is more intensely broken than many of the other dikes, possibly because it is the only dike essentially continuous in outcrop between Keystone and Reagan Camp faults (Fig. 1). It fractured in a manner which produced a host rock permeable to invading ore solutions. A few horizons in the Naco limestone likewise fractured in a favorable manner but most of the limestone did not.

This second period of pre-ore faulting produced a general N 70°–85° E shear direction with tension fractures of about N 55° E. Mineralization was deposited within these shear and tension fractures (see Fig. 6).

The relation of mineralized fractures to major faulting is clearly seen in the mine workings, especially the 6th level near the Ore Body fault. Shear and tension fractures resulting from this fault's movement are mineralized as sulfide stringers. Following mineralized tension fractures along their strike to the east, they are found to swing into weakly mineralized N 35° E fractures, shortly changing to barren north-south breaks.

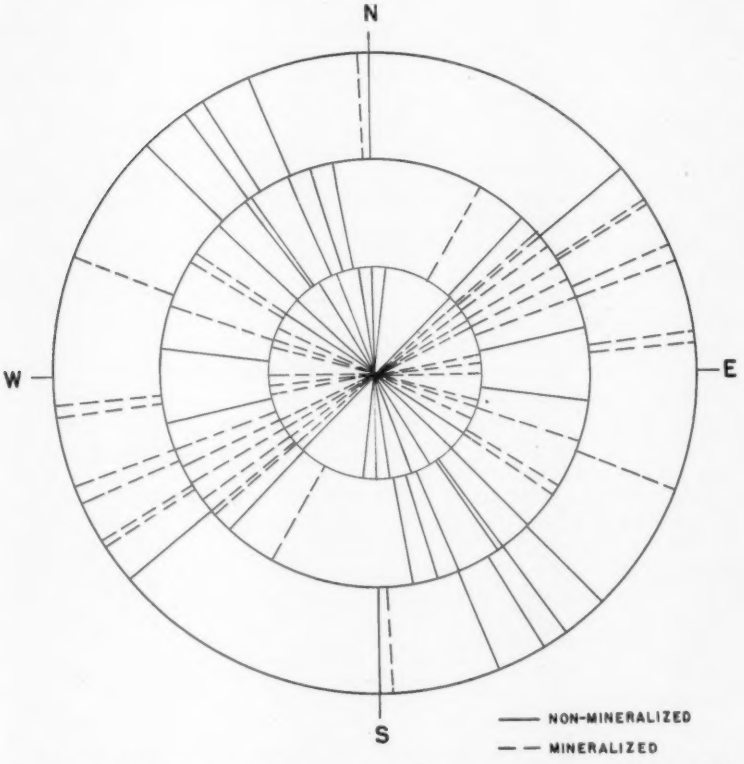

FIG. 6. Diagram of fault, shear zone, fracture directions. (Major within outer circle, moderate intermediate, minor inner, design suggested by B. S. Butler.)

Presumably ore solutions penetrated upward along the major north-south faults, and probably some of the major shear zones such as North dike.

Ore solutions, from the deep-seated Central Arizona batholith source in the vicinity of the North dike, ascended along the Ore Body fault and encountered the permeable shear and tension fractures of North dike. Ores

were deposited in this favorable host and rarely in the adjacent limestone. Closely spaced breaks concentrated mineralization into ore bodies.

Both Keystone and Ore Body faults show prominent mineralization stain and silicification along their outcrops. Underground, the Ore Body fault zone was not seen to be mineralized but sizable ore bodies occur nearby.

The limestone replacement deposits apparently had an origin similar to those in the porphyry. A strong suggestion of associated north-south échelon offset faulting is indicated by the bending of North and South dikes near the Discovery ore body (Fig. 1). Mineralization may have penetrated upward along this north-south zone. Upon encountering the shattered and permeable Naco limestone the solutions migrated laterally to form the Discovery and Massive Pyrite ore bodies. Southward this area aligns with a strong north-south fracture zone showing prominent mineral stain.

The north contacts and shear zones of the South and Seventy Nine dikes may have acted as a partial solution channel for the up-dip mineralization of the Discovery and Massive Pyrite ore bodies (Fig 5). The main shear zones of the North dike may also have been channelways for ore solutions.

Post-ore.—The Main fault, largest of the post-ore breaks, displaces the Discovery and Massive Pyrite ore bodies. Reconstructing the pre-faulting position of the mineralized beds places the Massive Pyrite body higher in the geologic section than the Discovery ore body. It appears that there are two favorable replacement zones within the lower part of the Naco limestone.

Small scale post-ore movement is abundant throughout the sulfide ore bodies associated with North dike.

Hypogene Ore.

All the hypogene ore bodies are very similar mineralogically. The main ore minerals are galena and sphalerite in about equal proportions with associated pyrite and minor amounts of chalcopyrite. The zinc content is slightly higher on the 7th level than on th 6th level. Silver is present as "argentiferous galena." The ore mined averages about 30 percent combined lead-zinc values with approximately one percent copper.

Ore Deposition.—Replacement was the dominant process in deposition of the Seventy Nine mine ores. The ore solutions selectively replaced impure calcareous shale beds to form the bed replacement ore bodies.

Within the intensely faulted and sheared rhyolite porphyry, ore was deposited along pre-existing fractures with some replacement of the host rock. Bain [11] has shown that replacement deposits are associated with moderately tight fissures rather than sizable open fractures. This allows capillary action to function, aiding circulation of the ore solutions within the host rock. The porphyry ore bodies consist of mineralized fractures spaced so closely together that commercial ore has been formed.

Between the sulfide ore stringers are bands of altered wall rock and much argillized material.

[11] Bain, G. W., The mechanics of metasomatism: Econ. Geol., vol. 31, pp. 515–526, 1936.

Age of Mineralization.—Ore deposition closely followed the second period of pre-mineral faulting and may have begun before it entirely ceased. The mineralization is postulated to be of Laramide (probably Early Tertiary) age.

Wall Rock Alteration.—Microscopic examination of the rhyolite porphyry from the mine workings reveals much sericitization of the feldspars with the original biotite bleached and replaced by muscovite; both the result of hydrothermal action. The porphyry, altered a white to light tan color, is characterized by large phenocrysts of quartz, with smaller and more abundant phenocrysts of altered feldspar. Associated with the ore bodies are angular blocks of porphyry showing a complete gradation from the outer completely altered material to a core of fresh porphyry. Much argillized material in the form of stringers is associated with the altered porphyry.

Solutions which followed the main period of mineralization silicified some sections of the rhyolite porphyry dike and certain limestone beds. Large silica bodies crop out in the area and one such non-mineralized mass was found on the 7th level.

Paragenesis.—The minerals of the Seventy Nine mine show evidence of having been deposited in a definite but interrupted three-stage sequence. The accompanying chart (Fig. 7) tabulates this order as determined by microscopic examination of representative polished sections.

The earliest and most widespread mineral is pyrite. Its deposition ceased before that of the other minerals began. Pyrite was shattered and subsequently invaded by the second stage of mineralization.

Microscopic examination commonly reveals "exploded bomb structure"; many grains show embayments or veinlets filled with sphalerite, galena, quartz or supergene cerussite.

Polished sections revealed embayments and veinlets of galena parallel to cleavage directions of sphalerite, indicating an earlier origin for the sphalerite. Precipitation of the sphalerite was followed almost contemporaneously by galena and chalcopyrite.

Galena is invariably associated with sphalerite. Embayments and veinlets of galena cutting sphalerite show the latter to be the earlier mineral.

Chalcopyrite is invariably associated with galena and sphalerite. Microscopic examination shows it present as small blebs and grains scattered through most specimens of sphalerite and forming mutual boundaries with galena grains. Hence the galena and chalcopyrite are regarded as essentially contemporaneous.

Some silver values have been present in the ore through the life of production. Microscopic examination reveals no identifiable silver mineral in the sulfide ore. The silver apparently occurs as "argentiferous" galena and has not formed as a separate mineral. Guild [12] has shown that galena will absorb up to 0.10 percent silver before a separate mineral, argentite or stromeyerite, will form. The silver content of the Seventy Nine mine ores amounts to less than one percent of the total lead content.

[12] Guild, F. N. *in* Fairbanks, E. E., Laboratory Investigation of Ores, McGraw-Hill Book Co., p. 237, 1928.

Following the second surge of mineralization, further movement shattered the pre-existing sulfides and subsequent solutions deposited abundant quartz as stringers and veinlets cutting all hypogene minerals.

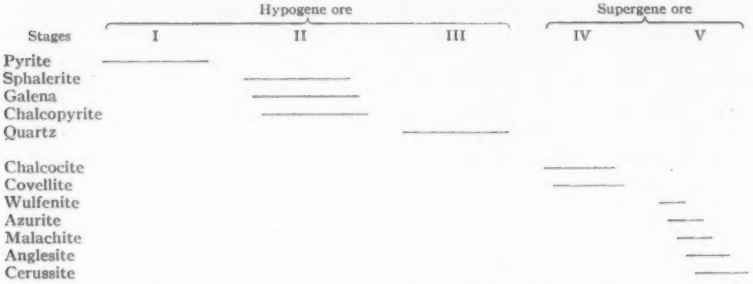

FIG. 7. Diagram showing the sequence of mineralization, Seventy Nine Mine.

Supergene Ore.

Oxidation and Supergene Enrichment.—The Discovery, upper parts of the Massive Pyrite, and North dike ore bodies show similar conditions of oxidation and enrichment. The demarkation of this zone is not sharp, but grades both horizontally and vertically, showing the effect of increased permeability for circulating ground water (Fig. 4).

Emmons [13] has listed the order of oxidation for such a deposit as first sphalerite, followed by chalcopyrite, pyrite and galena in the order named. Subtraction of the zinc, copper, and iron and the alteration of galena, initially to anglesite and subsequently to cerussite, has produced supergene ore at the Seventy Nine mine. The relatively insoluble lead products have undergone little transportation from their original position.

Oxidation has been active since the ores were deposited in Laramide (probably Early Teritiary) time. Erosion of the Upper Cretaceous volcanics, which probably covered the area in Early Tertiary time, with the subsequent formation of the Gila conglomerate in the fault troughs speeded oxidation of the ore bodies.

Paragenesis.—The following supergene minerals have been identified in the Seventy Nine mine: anglesite, azurite, brochantite, cerussite, chalcanthite, limonite, malachite, manganite, melanterite, psilomelane, and wulfenite.

The oxidized copper minerals are not sufficiently abundant to constitute copper ore. Chalcanthite and brochantite are sparingly associated with pyrite; manganese oxides are common and wulfenite is not present in sufficient quantities in the oxidized zone to constitute ore. Limonite occurs as a brown stain on the limestone and gangue minerals, as small stringers in the fault material, and as pseudomorphs after pyrite. Microscopic examination of the ores determined the paragenetic relationship as listed in the diagram (Fig. 7).

[13] Emmons, W. H., The Principles of Economic Geology, McGraw-Hill Book Co., p. 126, 1940.

Chalcocite occurs as small grains in minor amounts within the sphalerite and as small supergene veinlets.

Covellite in minor amounts is associated with the oxidation products of galena. Microscopic grains with feathery edges occur along cleavage cracks in galena, as replacements within anglesite, and along anglesite-galena contacts.

Anglesite occurs as dark concentric rings around the primary galena where replacement is not complete.

Cerussite is the most abundant oxidized ore mineral; it constitutes rich ore throughout the oxide zone. Cerussite occurs most commonly as earthy white or yellowish masses, commonly with a sandy texture (sand carbonate), and also in colorless crystal groups.

Classification of Ore Deposits.

The replacement vein and bed replacement deposits of the Seventy Nine mine would fall within the range of the mesothermal type according to Lindgren's classification.[14]

U. S. Corps of Engineers,
Sacramento, California,
Aug. 20, 1948.

[14] Lindgren, Waldemar, Mineral Deposits, McGraw-Hill Book Co., p. 212, 1933.

GEOLOGY AND GROUND WATER OF THE AZAPA VALLEY, PROVINCE OF TARAPACÁ, CHILE.[1]

GEORGE C. TAYLOR, JR.

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ABSTRACT.

The Azapa Valley lies in the extreme northern part of Chile in the Province of Tarapacá. Ground water in the valley has been developed extensively from springs, infiltration galleries, and wells for the irrigation of olive and citrus groves and other crops. The city of Arica and small industries in that vicinity also obtain water supplies from wells and infiltration galleries. Because of ideal conditions for the growing of crops and the present economic necessity for increased food production in northern Chile, the use of ground water for irrigation has gradually increased during the past several years and promises to continue to increase.

The Azapa Valley and adjacent uplands are underlain by rocks of the "Porphyritic" formation of Jurassic and early Cretaceous age, the "Liparitic" formation of probable Miocene age, and Pleistocene and Recent valley fill. The Azapa Valley was formed by the downcutting of the Río San José in rocks of the "Porphyritic" and "Liparitic" formations—probably during late Pliocene and early Pleistocene time. Later in the Pleistocene the Río San José began to alluviate the Azapa Valley. This process of filling has apparently continued to the present.

The "Porphyritic" formation includes a heterogeneous series of intercalated volcanic and marine sedimentary rocks. Among the volcanic rocks are porphyritic andesite and latite lavas, tuffs, and breccias. The sediments include limestone and shale and some sandstone. None of the rocks of the "Porphyritic" formation is water-bearing in or near the Azapa Valley.

[1] Published with the permission of the Director of the Geological Survey, U. S. Department of the Interior.

The "Liparitic" formation includes interbedded volcanic and continental sedimentary rocks. Rhyolite and dacite lavas, tuffs, breccias, and agglomerates make up the volcanic facies of the formation. The continental sedimentary rocks include semiconsolidated clay, siltstone, sandstone, and conglomerate. Most of the rocks of the "Liparitic" formation are impervious or yield only meager supplies of brackish or salty water in and near the Azapa Valley.

The Pleistocene and Recent alluvial fill of the Azapa Valley is composed of intercalated lenses of clay, silt, sand, and gravel. These deposits contain a zone of saturation that is sustained by infiltration from floods of the Río San José from December through March. The upper limit of the zone of saturation is marked by a water table which locally reaches the surface in springs and generally lies within 25 meters of the surface in wells in most of the Azapa Valley. Where present in the zone of saturation the coarse-grained facies of the alluvium yield moderate to large supplies of good water to springs, wells, and infiltration galleries. The individual yields of springs range from a few liters to about 25 liters per second. Existing wells in the valley yield from a few liters to 32 liters per second with pump.

In 1946–47 the use of ground water for irrigation from springs, infiltration galleries, and wells was approximately 15,000 cubic meters per day during a growing season of about 5 months. The city of Arica during 1946–47 used an average of about 1,700 cubic meters per day obtained from an infiltration gallery and wells.

INTRODUCTION.

THE Azapa Valley lies in the extreme northern part of Chile. Arica (population 12,939), located at the mouth of the valley, is the principal city. It is an important seaport and the terminus of railroads to Tacna, Perú, and La Paz, Bolivia. It is connected by the Chilean National Air Line with Santiago. The villages of Azapa Grande, Las Maitas, and Pago de Gómez are the only other populated centers of importance in the valley.

In November, 1946 the writer, in company with Sres. Sergio Ojeda J. and Mariano Allende U. of the Chilean Development Corporation (Corporación de Fomento de la Producción) and Captain Roberto Oliva R. of the Chilean Army, made a brief study of the geology and ground-water conditions of the valley. This work was part of a larger program of ground-water studies in northern Chile by the writer, of the U. S. Geological Survey, assigned to the Chilean Development Corporation. The work was carried on under the general direction of Sr. Francisco Javier Domínguez, Chief of the Irrigation Section of the Corporation.

The writer is much indebted to Sr. Ojeda and to Sr. Ricardo Hucke, engineer of the Chilean Department of Irrigation, Bureau of Public Works, in Tarapacá Province, for maps, plans, well logs, and other pertinent ground-water data placed at his disposal. He is also indebted to the authorities of the Ministry of National Defense for transportation furnished for the field work. The present report was reviewed and criticized by members of the U. S. Geological Survey.

Irrigation from wells has been practiced in the Azapa Valley for many years, and the use of infiltration galleries and natural springs for irrigation may date back to the epoch of Inca domination. The present study was made to

determine the general ground-water conditions of the valley and the feasibility of extending present ground-water developments for the irrigation of additional lands.

TOPOGRAPHY AND DRAINAGE.

The Río San José, which drains the Azapa Valley, is the outlet for an extensive fluvial system (Fig. 1). The headwaters of this system are on the

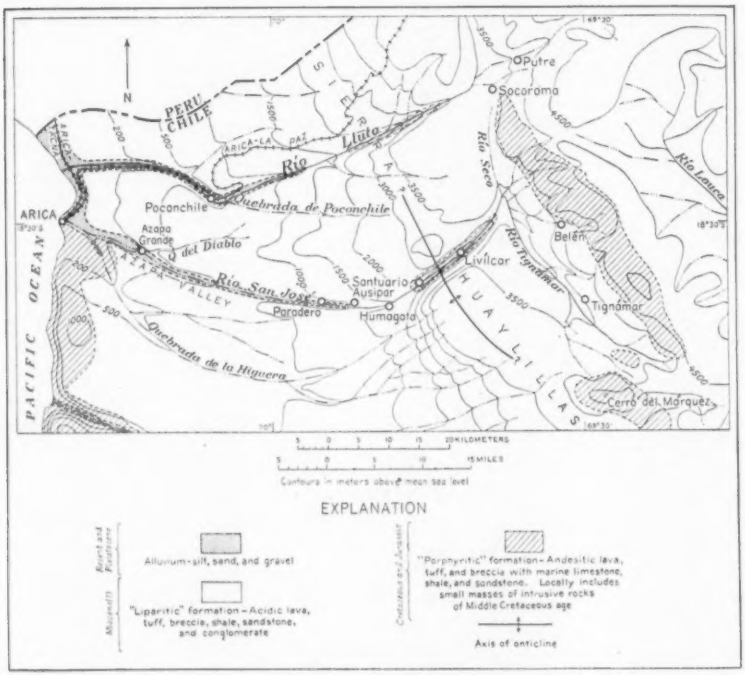

FIG. 1. Map of the Azapa Valley and adjacent region in the Province of Tarapacá, Chile, showing the general geology and topography.

western flanks of the Central Range of the Andes at elevations of 4,000 to 4,500 m above sea level. They unite principally in the Río Tignámar, which flows northwest some 40 km—first through an open highland valley and then through canyons and gorges to a junction with the Río Seco. The union of these two streams forms the Río San José, which flows for about 110 km—first southwest and then west-northwest to the sea. In the upper part of this course the river is entrenched in a gorge which attains a depth of about 1,500 m where it crosses the Sierra Huaylillas near Livilcar. From this point down-

stream to Ausipar the valley bottom is only a few tens of meters wide. Downstream from Ausipar the width of the valley bottom gradually increases to a maximum of about 2,000 m near Arica.

Between Ausipar and Arica the Azapa Valley is cut below the surface of a high, sloping plain or pampa that is the northern extension of the Pampa del Tamarugal or longitudinal depression of the central part of Tarapacá Province. This plain slopes evenly westward from an elevation of about 2,000 m at the base of Sierra Huaylillas to an elevation of about 700 m at the eastern base of the Coast Ranges (Fig. 1). In El Morro de Arica the Coast Ranges disappear, and the plain reaches the sea to the north of this point. At Ausipar the Azapa Valley is cut some 500 to 600 m below the plain surface, but at Azapa Grande the valley is only about 300 m deep. From Livílcar to Arica the average downstream gradient of the valley bottom is about 19.8 m to the kilometer.

The Río San José is a perennial stream as far down its course as Ausipar (Fig. 1). Throughout the year it carries a small permanent flow, all of which is diverted for the irrigation of small farms. In late November, 1946, at the time of lowest discharge, the flow of the stream was estimated at 75 liters per second near Livílcar. The low-water flow of the stream is sustained by small permanent springs that rise in its upper watershed.

Below Ausipar the Río San José is an ephemeral stream which carries only the water of the floods that result from summer rains in its upper watershed. Such floods generally occur from December through March. During peak stages they may attain flows of several tens of cubic meters per second. The water of major floods may reach the sea, but in minor floods the water is diverted for irrigation or soaks into the stream channel before reaching the sea. During years with normal precipitation in the headwater areas one to three floods may be expected, but in dry years the entire rainy season may pass without a flood in the lower course of the stream. At Las Riveras (Fig. 2) it is reported that flood waters may normally be observed in the stream channel during a total of about 30 days in the period of December through March. Individual floods may last 10 to 15 days at a stretch.

CLIMATE.

The climate of the Azapa Valley and of the drainage basin of the Río San José is characterized by extreme aridity. Rainfall in all parts of the basin is relatively scanty and varies in quantity largely with altitude. In most of the lower parts of the basin the average annual rainfall is less than 10 mm, and in much of the basin it is less than 1 mm. At Arica during the 31 years from 1912 to 1942, inclusive,[2] the only rainfall heavier than 2 mm was one of 10 mm recorded in January 1918; one or more rainfalls of 2 mm or less were registered in each of 7 other years during this period. Such light precipitation, however, is largely condensation from heavy fogs that does not have the character of true rain.

[2] Keller R., Carlos, El Departamento de Arica: Censo Económico Nacional, vol. I, p. 20, Zig-zag Press, Santiago, 1946.

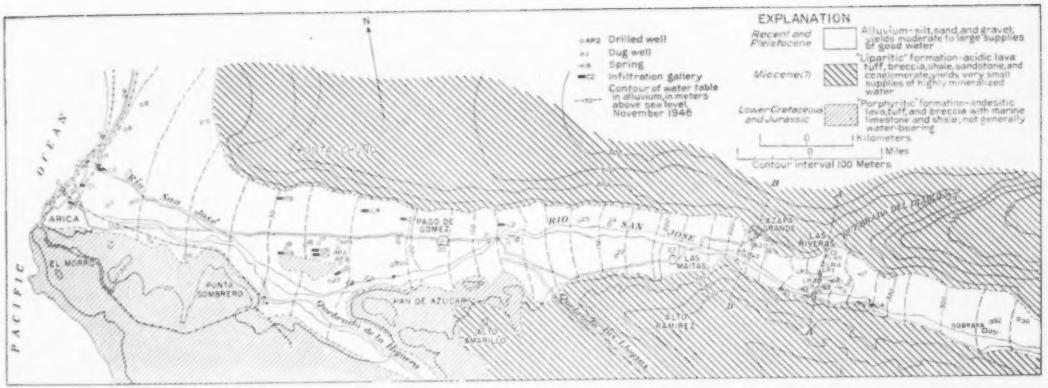

FIG. 2. Map of the Azapa Valley, Province of Tarapacá, Chile, showing the general geology, contours of the water table in the alluvium, and the location of typical wells, springs, and infiltration galleries.

Below an elevation of 2,000 m the annual rainfall is not sufficient to sustain even the most drought-resistant plants, but with increasing altitude the rainfall becomes sufficiently abundant to support a flourishing xerophytic vegetation. At elevations above 4,000 m (Fig. 1) on the Central Range of the Andes the average annual precipitation is of the order of 275 mm. This precipitation occurs in short but intense convectional storms of rain, hail, or snow during the months of December through May. January is generally the month of heaviest precipitation. Owing to the local nature of convectional storms, the precipitation registered from year to year at any one station may vary 200 to 300 percent from normal. According to Keller,[3] the annual precipitation appears to follow wet and dry cycles of 7 to 11 years' duration.

GEOLOGY.

General Features.

The rocks of the Azapa Valley and of the adjacent uplands may be grouped into three principal geologic units according to age (Fig. 1). The oldest of these is the so-called "Porphyritic" formation (Formación Porfirítica)[4] of Jurassic and early Cretaceous age. The "Porphyritic" formation includes beds of marine limestone, shale, and sandstone intercalated with andesitic and latitic lava, tuff, and breccia. Locally in the region of Cerro del Márquez (Fig. 1) the "Porphyritic" formation is intruded by small stocks of igneous rocks of probable middle Cretaceous age.

The second of the principal geologic units is the "Liparitic" formation (Formación Liparítica)[5] of probable Miocene age. This formation includes a heterogeneous series of fluvial and lacustrine semi-consolidated clays, siltstones, sandstones, and conglomerates that are in places intercalated with rhyolitic and dacitic lava flows, tuffs, and breccias.

Youngest of the three geologic units is the Pleistocene and Recent alluvial fill of the Azapa Valley. The fill is composed of intercalated lenses of unconsolidated clay, silt, sand, and gravel deposited by the Río San José.

Summary of the Geologic History.

The geologic history of the Azapa Valley and of the adjacent region in the Province of Tarapacá appears to include the following sequence of events:

During the Jurassic period and the early part of the Cretaceous period[6] parts of the Province of Tarapacá were covered from time to time by shallow embayments of the sea in which were deposited limestones, shales, and sandstones. Apparently during the same time there was considerable volcanic activity on adjacent land masses and even submarine eruptions in the submerged areas. The products of the volcanic activity include andesitic and

[3] Keller R., Carlos, op. cit., p. 138.

[4] Muñoz Cristi, J., and Flores Williams, H., Geologic map of Chile, scale 1 : 1,000,000 : Departamento de Minas y Petróleo y datos de diversos geólogos, Santiago, 1942.

[5] Idem.

[6] Weeks, L. G., Paleogeography of South America : Am. Assoc. Petroleum Geologists Bull., vol. 31, no. 7, pp. 1213–1215, July 1947.

latitic lava, tuff, and breccia with occasional continental sandstones and conglomerates. These rocks are intercalated with and in part overlie the marine sediments. This heterogeneous group of marine, volcanic, and continental rocks is known collectively as the "Porphyritic" formation (Formación Porfirítica).

In middle Cretaceous time [7] the rocks of the "Porphyritic" formation were strongly deformed and uplifted throughout the Province of Tarapacá. Accompanying the faulting and folding was the intrusion of stocks of igneous rock—chiefly granite, granodiorite, and diorite. These rocks appear locally near Cerro Márquez and in the ridge to the east of Belén and Tignámar but were not observed in the Azapa Valley or in the adjacent uplands. During late Cretaceous time, the upland developed by the middle Cretaceous deformation was reduced by erosion to a peneplane.

In early Tertiary time the rocks of the province were dislocated by normal faults—chiefly along lines trending north-northwest. The great longitudinal depression that lies between the Coast Ranges and the Andes of Tarapacá Province apparently was formed at this time. Evidently it is an elongated tectonic trough or graben dropped down on bordering faults. In the region of the present Coast Ranges and in the Andes region fault-block ridges separated by fault basins resulted from the structural movements. In the Coast Ranges the faults generally strike to the north, but in some localities faults that trend northwest or even west occur. According to Brüggen [8] the climate of northern Chile, which had previously been pluvial, became very dry and remained so for most of Tertiary time. As a consequence of this condition, the ephemeral streams were not generally capable of carrying their sediment loads to the sea but instead deposited them in depressions between the fault ridges.

In the middle Tertiary, probably in Miocene time, widespread volcanic eruptions occurred in the Andean region of Tarapacá Province. The eruptions apparently took place from extensive fissures located in the zone of the Bolivian frontier. Enormous quantities of rhyolitic and dacitic lava, tuff, and breccia issued from these fissures and spread east toward Bolivia as well as to the west. These materials, together with the sediments resulting from their erosion, filled ancient depressions and covered all but the summits of pre-existing hills and ridges. Cerro del Márquez and the ridge to the east of Belén and Tignámar (Fig. 1) are the summit areas of such hills and ridges. In the Andean region the materials filling the depressions are largely volcanic rocks. The lava flows did not generally extend much farther west than the present base of the Andes Range. In the region of the longitudinal depression the volcanic rocks are largely supplanted by a fill of semiconsolidated shales, siltstones, sandstones, and conglomerates that are contemporaneous with and in part the products of the destruction of the volcanic rocks. This heterogeneous assemblage of volcanic and sedimentary rocks is known collectively as the "Liparitic" formation (Formación Liparítica). It underlies

[7] Brüggen, Juan, El agua subterránea en la Pampa del Tamarugal y morfología general de Tarapacá, Imprenta Universitaria, pp. 7–15, Santiago (Chile), 1936.
[8] Idem, p. 9.

extensive areas in Tarapacá Province and in the region of the Azapa Valley (Fig. 1).

The longitudinal depression formed in early Tertiary time was at first without external outlet to the sea. For this reason the Andean streams flowing west during middle Tertiary time were ponded, and their sediments were gradually accumulated in a great fill. Eventually the surface of this fill was built up to the level of the lowest passes through the Coast Range. In this manner external drainage to the sea was established by way of passes now followed by the Lluta, Azapa, Chaca, Camarones, and Tiliviche Valleys. The pass through the Coast Range near the mouths of the present Lluta and Azapa Valleys was evidently low. The surface of the fill in this zone was graded to sea level at a shore line several kilometers west of the present coast. The fill surface in the passes farther to the south was graded to bedrock thresholds in the Coast Range.

In Pliocene time regional diastrophism affected the entire area of Tarapacá Province. The Andes Range was uplifted to approximately its present height in a great tectonic flexure. The western flank of the flexure is marked by a monoclinal slope in the "Liparitic" formation which dips westward into the longitudinal depression at angles ranging from 2 to 10 degrees. The anticline of Sierra Huaylillas (Fig. 1) is evidently a part of this monoclinal structure. As suggested by Brüggen,[9] the uplift along the axis of the Andean flexure may have been of the order of 2,500 to 2,700 m. During the same period of diastrophism the continental margin sank below sea level along the great fault marked by the present coastal escarpment of Tarapacá Province. To the east of this fault the Coast Ranges and the longitudinal depression were uplifted as a single structural block.

As a consequence of the Pliocene uplift the streams that had previously established outlets to the sea cut deep valleys through the Coast Ranges, across the longitudinal depression, and into the western flank of the Andes. In this manner the present valleys of Lluta, Azapa, Chaca, Camarones, and Tiliviche were formed. During late Pliocene and early Pleistocene time the lower valleys of Lluta and Azapa were cut to depths of the order of 30 to 45 m below the present grades of the Ríos Lluta and San José (Fig. 1). During the same time a platform of marine abrasion was apparently cut in the "Liparitic" formation between Arica and the Peruvian frontier (Fig. 1).

In middle or late Pleistocene time the Ríos Lluta and San José began to aggrade the lower reaches of their valleys, probably as a result of a gradual rise in sea level or possibly because of a slight downward movement of the continental margin. This cycle of alluviation has apparently continued to the present. The alluvial fill in the lower reach of the Azapa Valley is 45 m or more thick. It merges on the north with the similar alluvial fill of the Lluta Valley. Together the alluvium of these valleys blankets most of the wave-cut platform lying between Arica and the Peruvian frontier.

Volcanic activity was renewed at numerous eruptive centers in the Andean region of the province during the late Pliocene and continued intermittently to the present. This activity resulted in the upbuilding of many volcanic

[9] Brüggen, Juan, op. cit., p. 13.

cones and their associated eruptive fields of intermediate and basic lavas and pyroclastics. These cones and eruptive fields generally rest on a platform of the "Liparitic" formation, but in places they lie directly on the "Porphyritic" formation. The Pliocene and younger volcanics do not appear in Azapa Valley or in the adjacent uplands.

Geologic Formations and their Water-Bearing Properties.

"Porphyritic" Formation.—The rocks of the "Porphyritic" formation form the south side of the Azapa Valley from Arica for about 11 km. upstream (Fig. 2). They also reappear (1) in the vicinity of Livílcar and Santuario (Fig. 1), where the canyon of the Río San José crosses the anticline of Sierra Huaylillas, and (2) in the highland to the east of Belén and Tignámar.

In the vicinity of Arica the "Porphyritic" formation includes beds of marine limestone, sandstone, and shale intercalated with porphyritic andesite and latite lavas and tuffs. A section measured in a bluff at the eastern outskirts of Arica is typical.

SECTION OF THE "PORPHYRITIC" FORMATION IN BLUFF AT EASTERN OUTSKIRTS OF ARICA

	Meters
5. Latite, greenish gray; porphyritic, with phenocrysts of orthoclase and plagioclase feldspar and pyroxene	24
4. Limestone, dark gray; dense, with massive bedding	13
3. Andesite(?), dark brown; aphanitic	2
2. Limestone, dark gray; like unit 4	6
1. Latite, greenish gray; like unit 5	22
Base of section is alluvial-fill surface of Azapa Valley	
Thickness of measured section	67

About 1 km west of the measured section in the point of El Morro, unit 1 grades into "pillow" lava which apparently was laid down beneath water. The "pillow" lava overlies gray marine shale. Unit 2 grades into limy sandstones and shales in El Morro and overlies the "pillow" lava. According to Muñoz,[10] fossils of Middle Jurassic age have been collected from the marine strata in El Morro.

Near Livílcar in the canyon of the Río San José about 820 m of dark-gray shales and limestones of the "Porphyritic" formation are exposed. The shales are compact, fissile, and well stratified in beds 1 to 3 m thick. Thin beds of hard limestone occur occasionally in the section.

The rocks of the "Porphyritic" formation in the Coast Ranges near Arica are indurated and lack openings that might permit them to store or transmit water in appreciable quantities. Moreover, little or no rain falls in this area that might seep underground to form a zone of saturation in these rocks. In the headwater areas of the Río San José (Fig. 1) small but permanent springs issue from rocks of the "Porphyritic" formation. Such springs are apparently

[10] Muñoz C., Jorge, Rasgos generales de la constitución geológica de la Cordillera de la Costa, especialmente en la Provincia de Coquimbo, Anales del Primer Congreso Panamericano de Ingeniería de Minas y Geología. Geología, pt. 1, vol. 2, p. 286, Jan. 1942, Santiago (Chile).

maintained by water stored underground in fractures from precipitation at elevations of more than 3,000 m.

"Liparitic" Formation.—The rocks of the "Liparitic" formation abut against and overlie in part the rocks of the "Porphyritic" formation. They form the borders of the Azapa Valley where the "Porphyritic" formation is absent. Moreover, they underlie the alluvial fill of the valley floor, as well as a large part of the region adjacent to the Azapa Valley (Fig. 1). The "Liparitic" formation is composed of lacustrine and fluvial semiconsolidated clay, siltstone, sandstone, and conglomerate intercalated with rhyolite and dacite lava flows, tuffs, agglomerates, and breccias. A section measured at Punta Chuño 4 kilometers east of Arica is typical.

SECTION OF THE "LIPARITIC" FORMATION IN BLUFF OF PUNTA CHUÑO, 4 KILOMETERS EAST OF ARICA

	Meters
7. Rhyolite(?), blue-gray; with occasional beds of vitrified tuffs	49
6. Tuff, rhyolitic or dacitic, buff-colored, semiconsolidated	9
5. Clay, maroon and chocolate brown, tough, massive; with lenses of clayey sandstone	21
4. Tuff, rhyolitic(?), light yellow, semiconsolidated, friable	16
3. Dacite(?), bluish gray	6
2. Clay, maroon and chocolate brown; with occasional 1-meter beds of grayish-brown sandstone and conglomerate	58
1. Clay, like unit 5	26
Base of section at alluvial-fill surface of Azapa Valley	
Thickness of measured section	185

Farther inland volcanic rocks become increasingly abundant in the "Liparitic" formation, and the sedimentary strata become somewhat coarser in texture. This condition is demonstrated by a section measured on the south side of the Azapa Valley opposite Azapa Grande, about 16 kilometers inland from Arica.

SECTION OF "LIPARITIC" FORMATION IN BLUFF ON SOUTH SIDE OF AZAPA VALLEY OPPOSITE AZAPA GRANDE

	Meters
8. Dacite(?), gray; intercalated with vitrified tuff	85
7. Sandstone, fine-grained, soft, gray and yellow; with occasional beds of maroon clay	46
6. Rhyolite, light gray; with vitrified tuff like unit 5	52
5. Tuff, rhyolitic(?), vitrified, fractured	70
4. Tuff, rhyolitic(?), white, soft, friable, grading upward into light-yellow semiconsolidated tuff; one lens, 1½ m. thick, of maroon clay	6
3. Basalt(?), dark brownish black, dense, fine-grained	2
2. Clay, maroon and chocolate brown; alternating with 1-meter beds of gray silty sandstone and conglomerate; undulating contact with unit 1	6–17
1. Rhyolite, blue gray	23–24
Base of section at level of Río San José	
Thickness of measured section	300

At Paradero (Fig. 1), about 52 km from the sea, the "Liparitic" formation is composed almost entirely of volcanic rocks, although one prominent bed of stream-laid conglomerate was observed. A partial section measured by the writer on the north wall of the valley is typical.

PARTIAL SECTION OF THE "LIPARITIC" FORMATION ON THE NORTH WALL OF THE AZAPA VALLEY AT PARADERO

	Meters
11. Tuff, rhyolitic(?), yellow, semiconsolidated; with occasional angular fragments of rhyolite lava	60
10. Rhyolite(?), bluish gray	3
9. Tuff and ash, white and yellow, soft, semiconsolidated; with occasional thin beds of water-worn conglomerate and pumice	26
8. Rhyolite(?), bluish gray	9
7. Agglomerate, tuff, semiconsolidated; with subrounded 10- to 20-cm. fragments of gray rhyolite	9
6. Rhyolite(?), bluish gray	12
5. Breccia, explosion; fragments of red and gray rhyolite in a tuff matrix	6
4. Agglomerate, tuff; in upper part are beds of breccia with 10- to 20-cm. fragments of inflated red and gray rhyolite and lenses of stream-laid conglomerate	31
3. Ash, soft, white; with occasional thin layers of pumice	3
2. Conglomerate, stream-laid; in massive beds 2 to 3 m. thick; 5- to 30-cm. pebbles and cobbles in a coarse sand matrix	28
1. Tuff, rhyolitic(?), semiconsolidated, yellow; with numerous blocks and rhyolite lava up to 2 m. in diameter and occasional beds of soft white pumice	85
Base of section at level of Río San José	
Thickness of measured section	272

This section continues upward to the level of the pampa surface some 550 to 600 m above the Río San José. The rocks in the upper part of the valley walls are very similar to those of the measured section.

From Paradero the conglomerate bed, unit 2, slopes westward down the Azapa Valley with about the same gradient as that of the Río San José. It finally grades into sandstone and shale about half way between Paradero and Azapa Grande (Fig. 1). Upstream unit 2 gradually increases in thickness. At Ausipar it forms a single massive stratum 100 to 110 m thick of well-rounded pebbles, cobbles, and boulders in a coarse sand matrix. Still farther upstream near Santuario unit 2 abuts against a mass of porphyritic andesite of the "Porphyritic" formation. This mass is evidently part of an ancient ridge or hill once covered by the "Liparitic" formation and then partially exhumed along the canyon of the Río San José. At Livílcar the "Liparitic" formation attains a thickness of about 660 m and overlies marine shales and limestones of the "Porphyritic" formation. Between Santuario and Livílcar the "Liparitic" formation in the walls of the canyon of Río San José is composed almost entirely of rhyolite and dacite lava flows intercalated with beds of tuff, breccia, and agglomerate.

Because of their heterogeneous character the rocks of the "Liparitic" formation have different properties with respect to ground water. The volcanic facies of the formation include rhyolite and dacite lava flows and pyroclastic deposits of tuff, agglomerate, and breccia. The individual units of these rocks are generally discontinuous and have low permeability. For these reasons they may be able to store and transmit water only in limited quantities. The clay and siltstone members of the sedimentary facies of the formation are compact and fine textured and are therefore practically impervious. The sandstones may store or transmit water in small quantitiy if present in the zone of saturation.

Possibly the only member of the "Liparitic" formation that may have importance with respect to ground water in the Azapa Valley is the bed of stream-laid conglomerate which has been described as unit 2 in the Paradero section. This member is quite permeable and would yield considerable water to wells if it were present in the zone of saturation. However, it is almost completely dissected and drained by the canyon of the Rio San José. Moreover, it abuts against an ancient ridge of the "Porphyritic" formation near Santuario and, therefore, may be cut off from any important infiltration it might receive from rainfall at elevations above 3,000 m (Fig. 1).

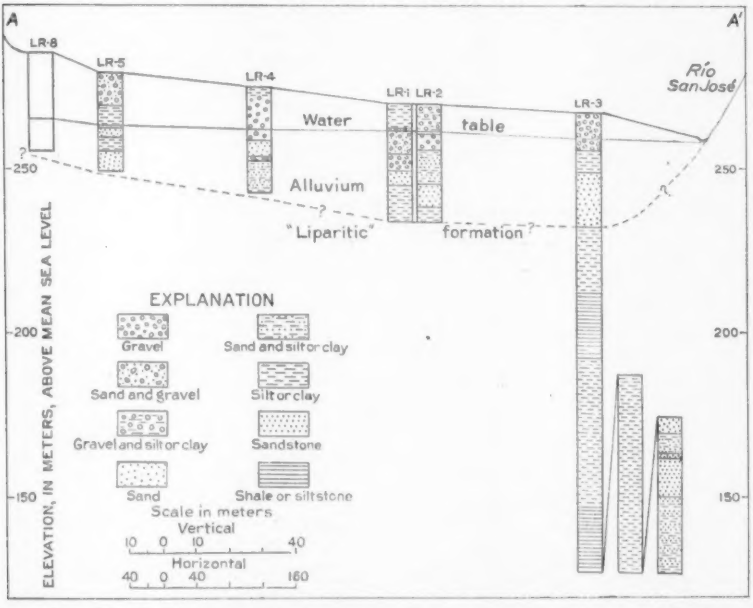

FIG. 3. North-south geologic cross section, A–A', through wells drilled on the Las Riveras plantation in the Azapa Valley.

Wells drilled in the lower part of the Azapa Valley by the Department of Irrigation, Bureau of Public Works, have revealed the character of the "Liparitic" formation beneath the Recent and Pleistocene alluvium. The deepest of these wells, LR-3, penetrated 213 m through rocks of the "Liparitic" formation between depths of 35 and 248 m (Fig. 3). Well A-4 (Fig. 4.) passed through 107 m of rocks of the "Liparitic" formation between 46 and 153 m. These wells and others drilled to shallower depths show that the "Liparitic" formation beneath the alluvial fill of the lower Azapa Valley consists largely of thick beds of clay or shale, siltstone, and soft fine-grained

sandstone. All these beds are either impermeable or have limited permeability and apparently are not water bearing.

That small quantities of water may move through these rocks of the "Liparitic" formation is indicated by well 29 in the Quebrada del Diablo (Fig. 2). This well is 44.1 m deep, and the water level stands 43.1 m below the surface. The well evidently taps water in saturated sandstone. However, the yield is very small, and the water is too salty to be used for domestic or stock purposes.

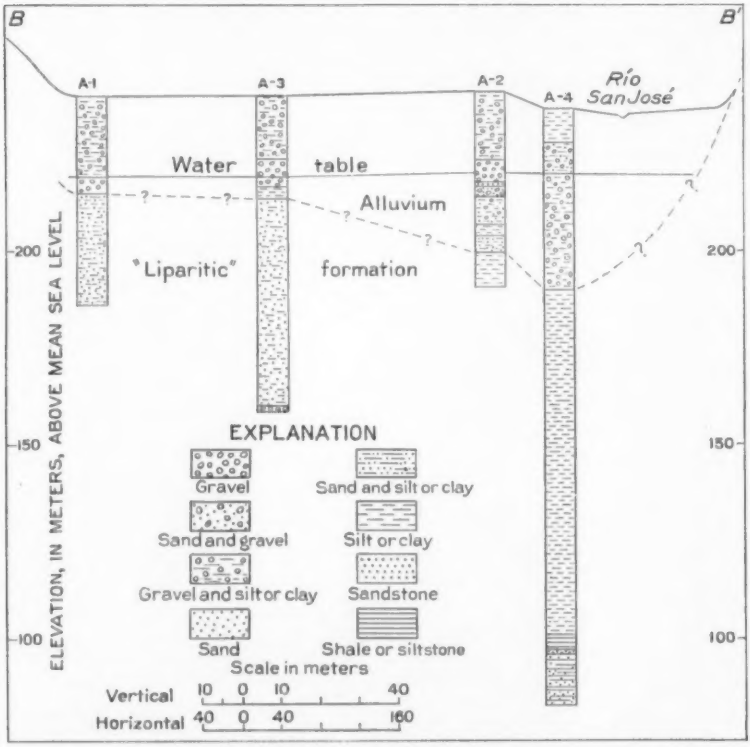

FIG. 4. North-south geologic cross section, B–B', through wells drilled on the Azapa plantation in the Azapa Valley.

Recent and Pleistocene Alluvium.—Recent and Pleistocene alluvium lies in a band 200 to 2,000 m wide along the floor of the Azapa Valley from Ausipar to Arica (Fig. 1). In the upper part of this stretch the alluvium is only a thin mantle of sediments overlying the "Liparitic" formation, but downstream its thickness gradually increases. Wells S-1 and S-2 drilled at Sobraya

(Fig. 2), 22 km from the sea, indicate that the alluvium is about 40 to 45 m thick in this vicinity. As suggested in section A-A′ (Fig. 3), the alluvium is 30 to 35 m thick at Las Riveras, 18 km from the sea. At Azapa Grande the thickness of the alluvium ranges from about 25 to 45 m, as indicated in section B-B′ (Fig. 4). Still farther downstream at well BV-1, only 8 km inland, the alluvium is 45 m thick, and at well AP-1 it is 46 m thick.

The characteristics of the Recent and Pleistocene alluvium and also of the underlying "Liparitic" formation are indicated in the logs of 14 wells and also in sections A-A′ and B-B′ (Figs. 3 and 4). These data show that the alluvium consists of intercalated lenses of unconsolidated clay, silt, sand, and gravel that grade into one another or disappear within short distances. Because these sediments were deposited from a stream that shifted its channel from time to time, there is a lack of lateral continuity in individual beds. The coarse materials were deposited in stream channels from running water, but the finer materials were deposited in the quiet waters that overflowed the channels. Thus the sand and gravel in the alluvium was laid down in narrow, elongate bands that follow the ancient stream courses. Characteristically the sediments of the alluvium are poorly sorted because they were deposited from torrential waters during floods of short duration. Thus in the fill it is common to find beds of boulder gravel with a large admixture of silt or clay.

The alluvium varies greatly in texture, and correspondingly the water-bearing properties of individual members of the alluvium also vary. The beds of silt and clay are generally impermeable and yield little or no water to wells and springs. On the other hand, the beds of sand and gravel are moderately to highly permeable and are generally saturated below the water table.

The water-bearing beds of sand and gravel in the Azapa Valley are not generaly well sorted. For this reason considerable differences in permeability occur that are reflected in the yields of wells. Among six wells on the Las Riveras line (Fig. 3) yields ranging from 16 to 32 liters per second were obtained. On the Azapa line (Fig. 4) yields ranging from 4.4 to 16 liters per second were obtained among four wells. In tests on wells AP-1, AP-2, and BV-1, located in the lower part of the Azapa Valley (Fig. 2), yields ranging from 24 to 30 liters per second were obtained. The yields of springs that rise from the sand and gravel members of the alluvium range from less than 1 liter to about 25 liters per second.

GROUND WATER IN THE ALLUVIUM.

The ground water in the alluvium of the Azapa Valley originates entirely from the infiltration of water from the Río San José. Such infiltration occurs chiefly during the months from December through March when floods pass down the lower course of the river. Most of the infiltration takes place in the stretch of valley downstream from Ausipar.

The ground water accumulated in the permeable beds of the alluvium moves down the valley along the slope of the water table. The shape, height, and slope of the water table in the alluvium in November 1946 are shown in Figure 2 by 10-m contours refered to sea level. As suggested by the con-

tours, the water table slopes down the valley with an average gradient of about 17 m to the kilometer. Near the mouth of the Quebrada de la Higuera, the ground-water flow in the alluvium is split for a short distance by a ridge of impervious rocks of the "Porphyritic" formation (Fig. 2).

The depth to water ranges from 0.95 m in well 1 to 34.60 m in well 26. In the springs that are not now dry the water table reaches the surface.

The ground water that moves down the Azapa Valley discharges naturally through springs and by evaporation and transpiration. The principal springs in the Azapa Valley are located near Las Riveras, near Pago de Gómez, and along the shore line from Arica for 3 to 4 km to the northeast. Undoubtedly some ground-water discharge also occurs in submarine springs just off shore from Arica. During the period 1941 through 1946, the total discharge of the springs above sea level in the lower Azapa Valley ranged between maxima and minima of about 80 and 10 liters per second, respectively. The maxima occurred during high stages of the water table in the alluvium, and the minima, during low stages. The general characteristics of the fluctuations in spring discharge are shown in Figure 5.

The discharge of ground water by evaporation and by the transpiration of plants was not evaluated quantitatively during the present study. Where the water table is at or near the surface, such as along the shore line to the northeast of Arica and around the springs near Pago de Gómez and Las Riveras, evaporation of ground water occurs. In these same areas are small growths of phreatophytic plants which evidently discharge some ground water by transpiration.

Ground water is discharged artifically at the surface by gravity from infiltration galleries and by pumps from wells. Infiltration galleries were once used much more extensively in the Azapa Valley than at present. Because of caving, they had to be cleaned frequently to insure the proper flow of water. With the advent of efficient pumps during the past 25 years, it has become more economical to pump water from wells than to maintain the infiltration galleries. Then, too, with declines of the water table in the past few years many of the galleries have gone dry. During the period 1941 through 1946, the total discharge from infiltration galleries in the valley ranged between limits of about 15 and 30 liters per second. The general characteristics of the fluctuations in discharge are suggested by the graph for gallery 2 (El Gallito) in Figure 5. It will be noted that the fluctuations correspond approximately to those of the springs, although the amplitude is not as great.

As based on a very rough estimate, the pumpage from wells between Sobraya and Arica was equivalent to a constant discharge of about 100 liters per second for a 5-month period during the irrigation season of 1946–47. The total ground-water discharge from the alluvium in the Azapa Valley by the flow of infiltration galleries and springs and by pumping from wells was estimated to be of the order of 175 liters per second during the irrigation season of 1946-47. This estimate does not take into account the discharge of ground water by submarine springs, or by evaporation and transpiration.

The quantity of the ground-water underflow through the alluvium of the Azapa Valley was not closely determined during the present study, for lack

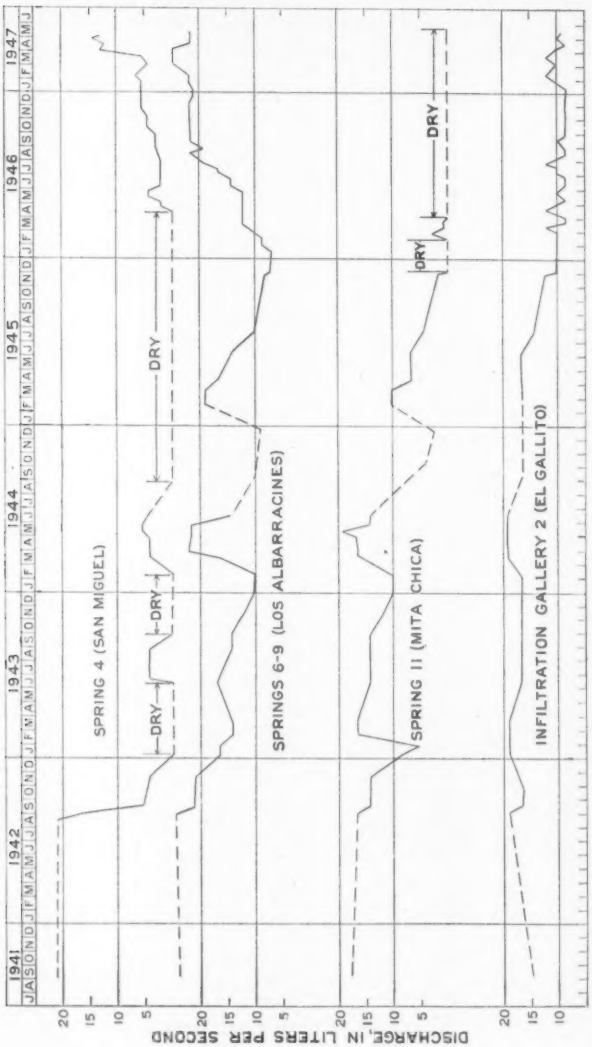
1941
1942
1943
1944
1945
1946
1947
J A S O N D J F M A M J J A S O N D J F M A M J J A S O N D J F M A M J J A S O N D J F M A M J J A S O N D J F M A M J J A S O N D J F M A M J
SPRING 4 (SAN MIGUEL)
DRY
DRY
DRY
SPRINGS 6-9 (LOS ALBARRACINES)
SPRING 11 (MITA CHICA)
DRY
DRY
INFILTRATION GALLERY 2 (EL GALLITO)
DISCHARGE, IN LITERS PER SECOND
20
15
10
5

FIG. 5. Graphs showing the fluctuations in discharge of springs and infiltration galleries in the Azapa Valley, 1941–47.

of basic data. However, a rough calculation, including as factors (1) the average cross-sectional area of the alluvium at Azapa Grande and Las Riveras, (2) the average gradient of the water table in this vicinity, and (3) an approximate value for the coefficient of permeability of the saturated materials, gave a figure of about 300 liters per second for the ground-water underflow through the alluvium in November 1946. This appears to be of the right order of magnitude, although a more precise determination of the underflow by quantitative methods would be desirable. From season to season and from year to year, the ground-water flow through the alluvium may vary greatly in quantity because it depends directly on the amount of infiltration from the floods of the Río San José. Thus the ground-water flow may vary perhaps 50 percent or more between cycles of wet and dry years.

The effect of infiltration from floods on the ground-water flow is reflected in the fluctuations of discharge of springs and infiltration galleries and of water levels in wells. The annual and seasonal fluctuations of discharge in three springs and in an infiltration gallery during 1941–47 are shown graphically in Figure 5. The graphs of springs 6–9 and spring 11 for 1944–45 show fluctuations that are perhaps typical for a pair of approximately normal or average years. The highest discharges occurred during the period of March to June. Apparently there was a lag of about 2 months between the passing of the first floods in December or January and the following period of high spring discharge. The lag probably corresponds to the time necessary for building up ground-water storage depleted during the preceding dry season. From June until the following January or February the graphs indicate a gradually decrease in the spring flow. This corresponds to the depletion of ground-water storage during the dry season by natural discharge and artificial withdrawals. The graphs in Figure 5 of springs 6–9 and spring 4 for 1946–47 may not show representative fluctuations because the discharge of these springs was artificially increased in 1946 by trenching of the spring heads.

As suggested in the graphs of Figure 5, the average discharge from springs in the Azapa Valley has decreased gradually during the 6 years of measurement by the Department of Irrigation. The over-all decrease has occurred in spite of the artificial increase in flow in 1946–47 of springs 6–9 and spring 4 brought about by trenching of the spring heads. Some of the springs such as La Media Luna (spring 10) have gone dry during the 6-year period. Several other smaller springs and infiltration galleries went dry even before 1941 and have not flowed during the 6-year period of observation. Water levels in wells have also shown an over-all decline during this period. According to the reports of the owners, the water level in well 18 has lowered some 5 to 6 m since 1932, and in well 19 about 4 to 5 m since 1928. The water level in well 21 has declined about 5 m since 1937.

These conditions may be due to one or the other of two factors or both: (1) a prolonged dry cycle in the drainage basin of the Río San José and (2) the increased pumpage from wells in the Azapa Valley. According to Keller,[11] precipitation in the Andes of Tarapacá Province occurs in wet and dry cycles of about 7 to 11 years' duration and has evidently been deficient

[11] Keller R., Carlos, op. cit., p. 138.

TABLE 1.

PARTIAL CHEMICAL ANALYSES OF WATERS FROM WELLS, SPRINGS, AND INFILTRATION GALLERIES IN THE AZAPA VALLEY.

Analyzed by Enzo Caviglia T., chemical engineer, in laboratory of Superintendence of Nitrate, Iquique. Samples collected November 20–22, 1946.

No.[1]	Analyses (parts per million)		No.[2]	Analyses (parts per million)	
	Chloride	Total hardness as $CaCO_3$		Chloride	Total hardness as $CaCO_3$
2	210	390	Well LR-1	105	240
3	200	280	Spring 6	100	260
4	190	360	Gallery 2	120	260
5	190	250	Gallery 10	200	380
6	200	360	Gallery 12	170	320
7	210	380			
8	180	330			
9	520	460			
10	3,010	1,020			
12	170	360			
14	630	460			
15	380	370			
16	120	290			
17	150	310			
19	160	320			
20	130	320			
25	120	310			
27	190	350			
28	120	270			
29	1,550	530			

[1] Dug well. Number corresponds to that in Figure 2.
[2] Drilled well, spring, or infiltration gallery. Number corresponds to that in Figure 2.

TABLE 2.

CHEMICAL ANALYSES OF WATERS FROM WELLS IN THE AZAPA VALLEY.

Analyzed by Enzo Caviglia T., chemical engineer, in laboratory of the Superintendence of Nitrate, Iquique. Samples collected November 20–22, 1946.

Map No.[1]	Owner or district	Analyses (parts per million)							
		Total dissolved solids	Iron (Fe) and alumina (Al_2O_3)	Calcium (Ca)	Sodium (Na) (calculated)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Total hardness as $CaCO_3$
9	Infusorial earth plant	1,567	Traces	206	373	183	650	520	460
10	Salt extraction plant	4,512	do.	524	1,264	61	1,100	3,010	1,020
14	Azapa munitions dump	1,744	do.	221	210	183	700	630	460
19	San Luis	538	do.	144	66	244	170	160	320
20	Pago de Gómez	445	do.	124	32	214	100	130	320
28	San Miguel	465	do.	106	59	183	140	120	270
29	Dolomite mine	[2]	[2]	[2]	[2]	61	1,200	1,550	530

[1] Number corresponds to that in Figure 2.
[2] Not determined.

for the past several years in the headwater areas of the Río San José. As a result, floods have not passed down the lower course of the river with normal frequency and volume. There has thus been a deficiency in the normal ground-water recharge to the alluvium of the Azapa Valley. The depletion of ground-water storage that has been reflected in diminished spring discharge and lowered water levels in wells may be due in large measure to below-normal recharge. However, pumpage from new irrigation wells constructed during the past few years has increased the amount of depletion of ground-water storage. Many such wells were put down when the springs or infiltration galleries began to decline in flow or failed to yield sufficient water for normal irrigation requirements.

CHEMICAL QUALITY OF THE GROUND WATER.

During the present study 32 water samples were taken from wells, springs, and infiltration galleries in the Azapa Valley. The object of the sampling was to determine differences in the chemical quality of the water that might reflect its geologic origin. It was also desirable to determine the suitability of the water for irrigation as well as for other uses. Of the 32 samples, 25 were analyzed only for hardness and chloride, and 7 samples were completely analyzed. The analyses were made in the chemical laboratory of the Superintendence of Nitrate in Iquique by Sr. Enzo Caviglia T., chemical engineer. The results of the partial analyses are shown in Table 1, and the complete analyses are given in Table 2.

The chemical quality of the normal ground water in the Recent and Pleistocene alluvium is typified by the complete analyses for wells 19, 20, and 28 in Table 2. There is apparently a gradual increase in the amount of dissolved solids in the water in the alluvium from Las Riveras to Arica. This is suggested by the increase in the total hardness and chloride content of the water, as shown in tabular form below:

Place of sample	Distance inland from shore line (kilometers)	Analyses (parts per million)	
		Chloride	Total hardness as $CaCO_3$
Spring 6	17.7	100	260
Well LR-1	17.0	105	240
Well 28	15.7	120	270
Well 25	11.5	120	310
Gallery 2	10.0	120	260
Well 20	8.4	130	320
Well 16	7.4	120	290
Well 17	6.6	150	310
Well 19	5.0	160	320
Well 12	1.4	170	360
Well 5	1.1	190	350
Gallery 12	0.7	170	320
Well 7	0.05	210	380

From this table it may be observed that chloride content of the water doubles between spring 2 and well 7, and the total hardness increases by about 120 parts per million.

Along the southern border of the valley near Arica are a few wells in the alluvium that have water with a higher content of dissolved solids than that characteristic of the normal ground water in the alluvium. Wells 14 (Table 2), 15 (Table 1), and 26 show this condition. The wells are located in alcoves along the valley border where the ground water may have stagnated. An additional increase in the dissolved solids in waters of these wells may have resulted from contact of the water with soluble materials in rocks of the "Porphyritic" formation in the valley border (Fig. 2).

A comparison of the analyses for wells 8 (Table 1) and 9 (Table 2) northeast of Arica suggest that between these wells a marked change takes place in the quality of the water in the alluvium. The water of well 8 is similar to that of the normal ground water in wells in the alluvium to the south and southeast. On the other hand, the water of well 9 has a high content of dissolved solids. However, this content is not as high as that of the water in the "Liparitic" formation. The possibilities thus exist that the water of well 9 may be (1) a mixture of the normal ground water of the alluvium with that of the "Liparitic" formation or (2) a mixture of connate or sea water with the normal ground water of the alluvium.

The water in rocks of the "Liparitic" formation is of decidedly inferior chemical quality, as indicated by the analysis for well 29 (Table 2). Although the upper part of well 10 is in alluvium (Fig. 2) the well may receive water from aquifers in the "Liparitic" formation, as suggested by the analysis in Table 2. The water from these wells is too salty to be used for irrigation, or for domestic or stock use.

A report by Scofield [12] has suggested limits for certain chemical characteristics of water used for irrigation. They are given in tabular form below:

SUGGESTED LIMITS FOR SAFE AND UNSAFE WATERS FOR IRRIGATION

(Parts per million)

Constituents	Lower limits	Upper limits
Total dissolved solids	700	2,000
Sulfate (SO_4)	192	480
Chloride (Cl)	142	355

Water with constituents whose concentration falls below the lower limits shown in the table are not likely to be harmful when used in ordinary irrigation. Most of the normal ground water in the alluvium as typified by the waters of wells 19, 20, and 28 (Table 2) would be in this category. Waters with constituents whose concentration falls between the upper and lower limits shown in the table may or may not cause injury to soils or crops, depending on (1) the concentration of the various constituents, (2) the characteristics of the land, and (3) the way the water is used. The waters of wells 9, 14 (Table 2), 15 (Table 1), and 26 would probably be in this category.

[12] Scofield, C. S., South Coastal Basin investigation, quality of irrigation waters: California Dept. Public Works, Water Resources Div. Bull. 40, pp. 21–24, 1933.

Waters with constituents whose concentration is equal to or exceeds the upper limits shown in the table are very likely to be unsuitable for irrigation because of their effects on plants and soils. The waters of wells 10 and 29 (Table 2) would be in this category. However, waters having even higher concentrations of dissolved solids are used successfully in some places where the soils are well drained and sufficient excess irrigation water is applied to flush out the salts and thus keep them from accumulating.

UTILIZATION OF GROUND WATER.

The ground water of the Azapa Valley perhaps has been developed as intensively for irrigation as that of any other zone of comparable size in Chile. Because of ideal conditions of climate and soil, olive and citrus groves produce abundantly, and most of the ground water developed in the valley is used for the irrigation of these crops. During the Inca domination and through the colonial epoch and period of Peruvian control, ground water was recovered for irrigation entirely by gravity from springs and infiltration galleries. These sources of water were always precarious, because the flow was subject to fluctuations caused by wet and dry cycles in the drainage basin of Rio San José. According to Keller,[13] some 15,000 olive trees were lost during the drought of 1909 to 1911 because of the diminished flow of the springs and infiltration galleries.

Not until fairly recent times has the pumping of water from wells for irrigation become general practice. At first the wells, all dug by hand, were fitted with crude windmills which yielded only meager quantities of water. Later more efficient lift pumps powered by Diesel or gasoline engines were installed in the wells. Only in recent years have drilled wells been constructed and equipped with modern turbine pumps.

Water supplies from wells may be more costly but at the same time are more dependable than gravity water supplies from springs and infiltration galleries. For example, a decline in the water table from a wet to a dry cycle means a marked lowering in the discharge of springs and infiltration galleries, but in wells it means no more than a temporarily lowered water level and increased pumping lift.

In recent years most of the infiltration galleries and the smaller springs in the valley have gone dry, and wells have been used to an increasing degree. Between Sobraya and Arica, there are perhaps 40 to 50 active irrigation wells, including those equipped with windmills. The dug wells range from 15 to 30 m deep and yield on the average about 5 to 10 liters per second with power pump. Since 1940 the Chilean Department of Irrigation, Bureau of Public Works, has supervised the drilling of 16 wells ranging from 30 to 247 m deep. The yields developed in tests of these wells range from 4.4 to 32 liters per second. Of these wells, 3 have been destroyed, 6 are idle, and 6 are equipped with pumps for irrigation or public use. At present the most productive well in the valley is well LR-1. This well is 36 m deep, with a static water level at 7.80 m. It yields 32 liters per second with a deep-well turbine pump.

[13] Keller R., Carlos, op. cit., p. 138.

During the irrigation season of 1946–47, lasting about 5 months, the average use of ground water from springs, infiltration galleries, and wells in the valley was approximately 15,000 m^3 per day. In 1946–47 the city of Arica also used an average of about 1,700 m^3 per day, obtained from infiltration gallery 12. This supply is to be supplemented by pumping from wells AP-1, -2, and -3.

CONCLUSIONS.

Additional development of ground water for irrigation in the Azapa Valley is considered feasible if new wells and pumping are properly distributed with respect to existing wells. Considerable ground water is now lost to the sea by spring discharge, both above and below sea level, along the coast for a distance of about 4 km to the north of Arica. In part, this water could be recovered for irrigation by pumping from new wells located in the zone lying north of the Arica-Pago de Gómez road, west of infiltration gallery 9, and east of wells 5 and 6 (Fig. 2). This zone is practically undeveloped agriculturally. It would be possible to obtain good water supplies for irrigation in this zone from wells about 40 to 50 m deep. The yields of wells in the zone would probably be comparable to those obtained in adjacent areas of the valley. It would not be desirable to locate new wells too close to one another nor too near existing irrigation wells. In order to avoid local interference between wells a spacing of the order of 500 m would be desirable.

The ground water in the valley near Pago de Gómez, Las Maitas, Azapa Grande, and Las Riveras appears to be fully developed by existing wells, springs, and infiltration galleries. Pumping from new wells located in these areas would eventually cause the springs and infiltration galleries to go dry.

As indicated by the present geologic study and by deep test wells drilled near Azapa Grande and Las Riveras, there appears to be little probability of finding untapped and productive aquifers in the "Liparitic" formation in the lower 30 km of the Azapa Valley. Hence it does not appear worth while to put down new wells to depths greater than 50 m or below the base of the Recent and Pleistocene alluvium.

Large quantities of water are lost to beneficial use when floods pass down the Azapa Valley to the sea during the rainy seasons of wet cycles. Considerable benefits to agriculture in the valley would result if this water could be stored for irrigation. Surface storage of such flood waters does not appear feasible because of the steep gradient of the valley and the large sediment load of the Río San José during floods. Considerable water could be stored underground by water spreading such as is practiced in California.[14] Between Paradero and Sobraya are large areas of gravelly, permeable ground that would be suitable for water-spreading basins. At the present stage of development of ground water in the valley, it is possible that the expense of constructing water-spreading canals and basins may not be economically feasible. However, this does not preclude the possibility that water spreading may be desirable in the future.

[14] Mitchelson, A. T., and Muckel, D. C., Spreading water for storage underground: U. S. Dept. Agr. Tech. Bull. 578, 1937.

The program of periodic measurements of spring discharges that has been carried on by the Department of Irrigation during the past 6 years is well considered. In order to complete the hydrologic observations in the valley it would be desirable to make periodic measurements of water levels in selected wells scattered along the lower valley. Such measurements could be made in conjunction with spring measurements and with observations of the approximate quantity and durations of floods. Such observations would have great value in the study of wet and dry cycles and in the prediction of changes in ground-water storage in the alluvium.

U. S. GEOLOGICAL SURVEY,
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SOME GLASS SANDS FROM NEW JERSEY.[1]

ALBERT S. WILKERSON AND JAY E. COMEFORO.

ABSTRACT.

Nineteen sand samples from the Coastal Plain of New Jersey are found to be amenable through beneficiation for use as high quality glass sand. Microscopical analyses and chemical analyses of treated sand fractions are presented.

INTRODUCTION AND ACKNOWLEDGEMENTS.

Although approximately $4,000,000 worth of sand is produced annually in New Jersey no detailed study has been made of the mineral or chemical composition of most of the sand deposits. If the quality of some of the sand produced could be improved through the application of beneficiation processes to satisfy the requirements for higher grade sands, the value of the material would increase accordingly. Furthermore, by proper methods of treatment deposits which are now neglected might be worked profitably. It is also believed that if the desired grades of sand can be obtained through use of beneficiation methods, industries which are now dependent upon sand may find it advantageous to establish or expand in New Jersey. This would create new markets for the material as well as a source of employment.

Knowledge of these facts prompted the Rutgers University Bureau of Mineral Research to undertake a detailed study of some New Jersey sands, tabulated factual results of which are presented in this paper. Nineteen sands are found to be amenable through treatment for use as high quality glass sand. Because glass sand specifications are the most stringent, sand capable of meeting these requirements may be assumed to be satisfactory for less demanding uses. Details of the exact location, ownership, present uses of the sands, field relations, methods of sampling, mineral composition by sieve fractions, percentage of grains rounded, percentage of grains containing inclusions, percentage of quartz grains coated by iron oxide or other impurities per sieve fraction, and the details of methods of beneficiation have been published by the Bureau.[2] All data were obtained from relatively few samples selected from a large area of sand deposits from the Coastal Plain and came from as far south as Cape May and as far north as Raritan Bay. In most cases they were chosen because of their geographical distribution in conjunction with the probability of their yielding to commercially feasible methods of beneficiation. The results are preliminary in that geographical coverage is partial and that all feasible beneficiation methods have not been applied.

[1] Printed by permission of the Director, Rutgers University Bureau of Mineral Research.
[2] Wilkerson, A. S. and Comeforo, J. E., Some New Jersey glass sands: Rutgers University Bureau of Mineral Research Bull. no. 1, pp. 1–156, 1948.

All sands were dried at 180° F for two days and then quartered through a riffle sampler containing 12 troughs. The final sample was in turn split, one portion used for screen and mineralogical analyses, and the other kept for purification treatment. Approximately 500 grams of sand were required for screen analysis.

After the results of the mineralogical analyses were obtained, beneficiation was attempted. If the fraction of sand to be examined was coated, washing was necessary. This was done by scrubbing the sand in a flotation cell

FIG. 1. Location of sand samples.

with 1 : 1 ratio of sand to water. One pound/ton of sodium hydroxide was added to this mix. The silt that washed off was removed by decantation and the procedure continued until the water remained clear. The washed sand fraction was then ready for additional treatment. The methods employed depended upon the impurities present. If the primary impurities were discrete grains of minerals with specific gravity of 3.5 or higher, tabling was attempted.

In this work a Wilfley laboratory model table with a 40 in. × 18 in. deck was used. The sand was tabled several times with changes made in the rate of feed of sand, amounts of water, and inclination of deck so as to determine the conditions necessary for best results. In all cases the aim was to ascertain

TABLE 1.

PERCENTAGE MINERAL COMPOSITION OF NINETEEN NEW JERSEY SANDS.

Mineral	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
quartz	98.3	96.3	99.8	99.8	99.5	99.5	99.5	99.6	99.5	98.5	99.0	98.6	96.6	96.5	98.8	99.4	98.9	99.1	97.4
apatite										tr									
biotite						tr													
carbonaceous matter														tr			tr		tr
calcareous shells	0.3	tr		tr							0.4								
chalcedony	0.4			tr	tr		tr		tr				tr	tr	tr				tr
chlorite									tr		tr		tr				tr		tr
corundum							?											tr	
diopside	tr										tr								
epidote		tr					tr				tr	tr	tr						tr
feldspar	0.5	tr	tr	tr	tr				tr	tr	tr	tr	tr	tr			tr		tr
garnet	tr	0.2				tr	tr				tr	tr		tr					tr
glauconite		tr					tr			0.8	0.1								
graphite														?					?
hematite	tr	tr		tr	tr		tr			tr	tr	tr							
hornblende		tr										tr	tr	tr					
hypersthene													tr						
ilmenite	0.1	1.3	0.1	0.1	tr	0.4	0.2	0.1	tr	0.2	0.1	0.7	tr	tr	0.1	0.3	0.6	tr	1.5
kaolinite			0.1	tr	tr		tr	tr	tr			0.3	1.5	tr	0.2	tr	0.1	tr	tr
kyanite													tr						
limonite	tr							tr											
magnetite	tr	tr			tr	tr	tr				tr	tr					tr	tr	
muscovite	tr	tr	tr	tr	tr		tr	tr	0.4		tr	0.3	1.1	0.8	tr	tr	0.1	0.8	0.3
phlogopite																			tr
pyrite		tr									tr			tr				tr	
rutile		tr	tr	tr	tr	tr	tr	tr		tr	tr	tr	tr	tr	tr	0.1	tr	tr	tr
sillimanite		tr										tr	tr						
spinel	tr																		tr
staurolite	tr	0.1		tr	tr		tr	tr	tr		0.2	tr	tr			tr		tr	tr
titanite	tr	tr		tr	tr			tr		tr	tr			tr		tr			
tourmaline	0.1	0.6	tr	tr	tr		tr	0.1	tr	tr	tr	tr	tr	tr	tr	0.1	0.1	tr	0.5
zircon	tr	0.1	tr	tr	tr	tr	tr	tr			tr	tr	tr	tr	0.1	tr	0.1	tr	0.2
zoisite													tr			tr			tr

the possibility of separating the quartz from the impurities and not primarily to obtain a high yield.

If tabling was unsuccessful, or if the specific gravities of the chief impurities were too low for a gravitational separation, flotation was tried. The procedure followed varied somewhat with the impurities present, but in almost every case a fatty acid was used as the collector in a basic circuit. A Fagergren laboratory test machine was used.

TABLE 2.

CHEMICAL ANALYSES OF TREATED SAND FRACTIONS.[1] PERCENTAGE OF TOTAL SAND ANALYZED. GRADE OF GLASS SAND OBTAINABLE AFTER BENEFICIATION.

Sand no.	Sieve fraction treated	Percentage of total sand	Grade of glass sand	SiO_2	Fe_2O_3	Al_2O_3	TiO_2	CaO	MgO	Loss on ignition
1	−20 +60	55	4	99.33	0.048	0.30	0.028	tr	none	0.32
2	−20 +100	96	2	99.15	0.023	0.49	0.058	0.05	tr	0.15
3	−40 +80	69	2	99.55	0.022	0.15	0.024	tr	none	0.15
4	−12 +40	61	2	99.28	0.027	0.22	0.021	0.03	tr	0.22
5	−12 +80	76	3	99.45	0.036	0.28	0.058	0.05	tr	0.15
6	+100	92	2	99.58	0.028	0.23	0.034	tr	tr	0.17
7	−20 +60	80	2	99.75	0.017	0.15	0.028	0.05	tr	0.05
8	−40 +80	69	4	99.25	0.044	0.25	0.020	0.05	tr	0.37
9	−20 +80	86	2	99.37	0.028	0.36	0.028	none	none	0.24
10	−20 +100	90	2	99.66	0.032	0.31	0.033	tr	none	0.01
11[2]	−20 +60	78	2	98.96	0.028	0.026	0.021	—	—	0.12
12	−20 +80	73	2	99.34	0.023	0.42	0.047	0.08	tr	0.19
13	−40 +80	83	3	98.60	0.021	0.77	0.100	0.25	tr	0.17
14[2]	−40 +80	97	3	98.94	0.024	0.373	0.038	—	—	0.48
15	−12 +40	65	2	98.88	0.030	0.32	0.032	0.05	tr	0.63
16	−20 +60	49	4	99.05	0.050	0.40	0.037	0.07	tr	0.35
17[3]	−20 +80	85	3	99.65	0.028	0.192	0.047	tr	tr	not det.
18	−30 +80	86	2	99.43	0.029	0.30	0.054	0.08	tr	0.12
19	−20 +80	79	3	99.12	0.037	0.63	0.037	tr	tr	0.17

[1] Chemical analyses, unless otherwise specified, by Sharp-Schurtz Co., Lancaster, Ohio.
[2] Chemical analysis courtesy of the Kimble Glass Company of Vineland, New Jersey.
[3] Chemical analysis courtesy of D. B. Lenny of the Pennsylvania Railroad Company.

Other methods of beneficiation appeared to lend themselves to the successful improvement of certain sands. The separation of mica from quartz may be carried out by water elutriation. This was done with several sands and the results were encouraging. The apparatus used consisted of three vats, the sizes being 265, 625, and 2715 cc. The sand was added to the first vat where the particles with the greatest mass settled out. The finer sand was retained in the second vat, and the mica and some very fine sand were collected in the third.

After a large percentage of impurities as discrete grains was removed, the quartz grains of many sands were still coated with iron oxide to an appreciable extent. In order to reduce the iron content to the lowest possible value the treated sand was acid leached. Acid leaching was conducted by adding sufficient 18 N. H_2SO_4 to liberally cover the sand. The mixture was then heated on a hot plate to aproximately 220° F for 90–120 minutes. The

acid was decanted off and the sand washed several times and then dried at 180° F.

The products obtained, after the final beneficiation process, were chemically analyzed. Unless otherwise specified, the chemical analyses were made by the Sharp-Schurtz Company, Lancaster, Ohio.

Additional methods or variations in the above procedures were necessary in special instances. The methods of beneficiation used for each sand depend on its composition. The methods studied include washing, screening, tabling, flotation, elutriation, ballmilling, and acid leaching.

Financial contributions toward the expenses of this investigation from the New Jersey State Department of Economic Development and the University Research Council of Rutgers University are gratefully acknowledged.

TABLE 3.

LOCATION AND AGE OF SANDS.

Sand number	Location	Age
1	Cape May Point	Recent, beach
2	Cape May City	Recent, beach
3	Dividing Creek	Cohansey (Tertiary)
4	Mauricetown	Cohansey (Tertiary)
5	Cedarville	Cohansey (Tertiary)
6	South Vineland	Cohansey (Tertiary)
7	Iona	Cohansey (Tertiary)
8	New Freedom	Cohansey (Tertiary)
9	Palmyra	Raritan-Magothy (Cretaceous)
10	Pemberton	Kirkwood (Tertiary)
11	Lavallette	Recent, beach
12	Manasquan	Kirkwood (Tertiary)
13	Englishtown	Englishtown (Cretaceous)
14	Jamesburg	Raritan-Magothy (Cretaceous)
15	Milltown	Raritan-Magothy (Cretaceous)
16	Old Bridge	Raritan-Magothy (Cretaceous)
17	Old Bridge	Raritan-Magothy (Cretaceous)
18	South Amboy	Raritan-Magothy (Cretaceous)
19	Woodmansie	Cohansey (Tertiary)

STATISTICAL DATA.

The percentages of the minerals present in each of the sands, obtained by mineral count, are recorded in Table 1. Usually more than 1,000 grains were counted from each weighed sieve fraction, but frequently several thousand were counted. The percentages are those of the sands as received. Table 2 presents, along with other data, chemical analyses of specified sieve fractions after beneficiation. Thus a direct comparison between chemical analysis and mineral composition cannot here be made.

CANNEL, BOGHEAD, TORBANITE, OIL SHALE.[1]

JAMES M. SCHOPF.

ABSTRACT.

The gradational interrelationship of coal with cannel, boghead, torbanite, and oil shale is reemphasized in view of contrary opinions expressed recently. An example from South Africa that has recently been studied in some detail is cited in illustration of how closely coal and torbanite may be related. The scientific classification of the carbonaceous rocks requires a broader basis of comparison than is generally adopted; authoritative statements cannot have very much weight unless supported by more correlated data than exist now.

THE terms cannel, boghead, torbanite, and oil shale have widely differing connotations to different persons, largely depending on the particular associations these persons have had with rocks so designated. There probably is no comparable series of terms of important scientific and commercial interest upon which such a diversity of authoritative pronouncement can be found. Attention was first focused on the difficulty in classifying these rocks scientifically in the celebrated Torbane Hill law suit of Gillespie vs. Russell in 1853, and probably it is fair to suggest, even now, that no single authority has a sufficient knowledge of the diversity of the problem to satisfy all modern requirements of critical definition. However, a recent author [2] has said, "it is now generally accepted that a torbanite differs from a coal so markedly that it must be regarded as a distinct class of mineral." In spite of this, good authorities and examples can be cited that would indicate an opposite view.[3, 4] The writer believes most of the rock types that have generally been referred to by the four names discussed here probably are members of a closely and complexly *intergradational series* and that coal, as such, is distinguished from them (if at all) only by some arbitrary degree of purity—a patently artificial boundary in the sense of genetic relationships.

The recent results of a micropetrologic examination of a South African commercial torbanite deposit, conducted under the auspices of the South African Council for Scientific and Industrial Research, may be cited as an example to indicate some of the reasons why torbanite is believed to have a positive relationship with coal and may best be regarded in that light for purposes of scientific classification.

[1] Published by permission of the Director, U. S. Geological Survey.

[2] Cadman, W. H., The oil shale deposits of the world and recent developments in their exploitation and utilization, reviewed to May 1947: Inst. Petrol., Jour., 34, p. 110, 1948.

[3] White, C. D., The carbonaceous sediments, esp. pp. 381–384, *in* Twenhofel, W. H., *et al.*: Treatise on sedimentation, 2d ed., Baltimore, 1932.

[4] Thiessen, Reinhardt, Origin of the boghead coals: U. S. Geol. Survey Prof. Paper 132–I, pp. 121–138, 1925.

The deposit mined at the Satmar (South African Torbanite Mining & Refining Co.) plant about 8 miles north of the town of Ermelo in southeastern Transvaal is about 53 inches thick. The upper 20 inches consists almost entirely of attrital coal, grades below into a sparsely banded layer 10 inches thick, which in turn grades through a moderately banded layer to the top of the torbanite bench about 3 feet from the top of the deposit. The torbanite layer proper is only about 14 inches thick, but about 2 inches of coal, classed as cannel according to Thiessen's criteria, occurs below it and is not distinguishable from the torbanite without special microscopic examination or chemical tests. An inch or less of banded coal is present at some places at the bottom of the bed. As far as the writer knows, this is the first study to be made on a quantitative basis of a complete bed including commercially mined torbanite and coal. The more detailed results of this study are to appear in a forthcoming memoir of the South African Geological Survey.

The distinctive microscopic feature, and the only one, that separates the torbanite layer from the rest of this coal bed is the abundance of the fossil remains of a colonial alga—the so-called boghead alga that Blackburn and Temperley [5] have shown to be botanically identifiable with the modern species of *Botryococcus braunii* Kütz. It includes the antecedent forms previously designated in paleobotanical literature as *Reinschia* and as *Pilla* and the form Thiessen mistakenly called *Elaeophyton coorongiana*. The presumed taxonomic differences in the fossil material are features resulting from extreme colonial polymorphy that are as well shown in modern cultures of the alga as in the ancient deposits.

Only a very few of the algal colonies are found in the banded coal above the torbanite. It is, of course, well recognized that scattered colonies of *Botryococcus* may occur in the attrital portion of banded coals. Cannel-bogheads and boghead-cannels, mentioned by Thiessen, include substantial numbers of such algae though usually not in sufficient numbers to be important for commercial distillation.

Aside from the algae, the other features of the torbanite are qualitatively similar to the coal of the bed. The most important similarity is in the "opaque" ground mass of the torbanite. This ground mass always has been a highly enigmatic material in torbanite, since it shows no distinctive characteristics of form, and only in areas of sections prepared to extreme thinness (less than 1 or 2 microns) does it transmit light in limited fashion. It generally appears grayish in such portions of the preparations or along "feather" edges of the sections.

The attrital portion of the sparsely banded layer of this bed shows the same material in abundance, and here it is in characteristic association with vitrinized streaks and lenticles that typify a number of Northern Hemisphere coals classed as splints or durains. There is no abundance of megaspore coats that some authors associate with the microscopy of durain, but such occurrence of spore coats is a "facultative" rather than "obligatory" characteristic of splint as Thiessen identified it. I am inclined to regard spore coats in much

[5] Blackburn, K. B., and Temperley, B. N., *Botryococcus* and the algal coals: Roy. Soc. Edinburgh, Trans., vol. 58, p. 841, 1936.

this same fashion with regard to the critical definition of durain. The one salient characteristic diagnostic of Thiessen's splint coal was a finely dispersed, extremely dense component, which he called *opaque attritus*. "Splint" coals, or "splint" layers, signify a concentration of *over 30 percent* opaque attritus, wherever this term has been critically used in work of the Coal Constitution laboratory of the U. S. Bureau of Mines, and this is probably the most precise usage that has yet been attached to it.

There is in this particular South African coal bed no question that the opaque matter in the banded portion is comparable in all its microscopic features with the microcomponent Thiessen called opaque attritus. The majority of it takes the form of amorphous opaque matter, but a little granular opaque matter and a small amount of fusain also are present. The opaque matrix of the torbanite layer is largely composed of opaque attritus exactly comparable with the amorphous opaque attritus of the banded coal above it in the bed.

This is a characteristic commonly, but not invariably, associated with the generally more diffuse occurrence of *Botryococcus* in American coals and is not unexpected to those familiar with the microscopy of coal. There are few places, however, where the torbanite is so conclusively identified by its actual commercial utilization and its natural relationship demonstrated by association in contact with an obvious coal deposit. Usually when algal deposits are closely associated with coal it is customary to regard them as boghead or as cannel, and they escape identification as torbanites because data from commercial distillation are not available. Fortunately Petrick [6] has presented chemical data regarding Satmar torbanite.

The distinction between cannels, bogheads, torbanites, and oil shales is very obscurely drawn. Most authors deal chiefly with one aspect or another of one of these nominal kinds of deposits and find it necessary to avoid a critical discussion of their interrelationships. The terms appear to the writer to have acquired, to some extent, overlapping and sometimes contradictory commercial, legal, chemical, petrographic, and geologic significance.

Let us hope with Mr. Cadman that the controversial classification and nomenclature of oil-yielding rocks will be settled before long. The writer is of the opinion, however, that the "authoritative" method is not more likely to serve the purpose in the future than when it was initially adopted in "settling" the boghead mineral dispute. A considered and fundamentally scientific program embracing chemical and micropetrographic and other viewpoints would probably prove more effective, however. Past studies have usually concerned themselves with limited materials for observation, based on some particular economic resource, as in Scotland or as in the region of the Green River formation in western United States. The techniques of comparison also have been restricted. Such limited studies cannot possibly serve scientifically for so essentially philosophical a subject as general classification. Lean as well as rich deposits must all be thoroughly considered, and data regarding a more balanced set of definitive characteristics should be included.

[6] Petrick, A. J., A contribution to the study of South African oil shales: Fuel Research Inst. Bull. 7, pp. 27–40, Pretoria, 1937 (reprinted from Chem., Met. Min. Soc. South Africa, Jour., vol. 37 (6), Dec., 1936).

Modern scientific studies now would have an advantage over those of past authorities, since there have been recent advances in fundamental techniques in physical instrumentation that may be brought to bear on the question.

The purpose of this paper has been simply to suggest that the controversial questions about classification of the carbonaceous rocks may not be as near a satisfactory solution as could be wished, although many persons assume these problems have all been solved. The problem of general classification has already existed for a long time, but it is likely to continue longer until more extensive and systematic studies have been completed.

U. S. GEOLOGICAL SURVEY,
WASHINGTON, D. C.,
September 24, 1948.

REVIEWS

Structural Geology of Canadian Ore Deposits—A Symposium. M. E. WILSON, CHAIRMAN. Pp. 948. Can. Inst. of Mining and Metallurgy, Montreal, 1948.

This monographic work was arranged by a committee of the Geology Division of the Canadian Institute of Mining and Metallurgy and was contributed to by 123 authors, each of whom knows his subject. It is an excellent example of fine team work and the Committee of M. E. Wilson, A. H. Lang, J. E. Hawley, V. Dolmage and H. C. Gunning deserve special praise.

Although the volume is called structural geology, the descriptions of each deposit cover all phases of the geology, with special emphasis on structural controls of ore. The volume covers essentially all districts and mines in Canada, and treatment is on a regional basis.

The arrangement and coverage is as follows: Chapter I, General Papers: The Cordilleran Region of Western Canada, by A. H. Lang; The Canadian Precambrian Shield, by J. E. Gill; Mineral Occurrences in the Appalachian Region of Canada, by F. J. Alcock; Relationships of Minor Structures to Gold Deposition in Canada, by Frank Ebbutt. The following three chapters follow the three regions given above.

Chapter II includes the Cordilleran Region and is divided into 3 parts: Coastal Belt, Interior Belt, and Rocky Mountain Belt, and under each are described the individual districts and mines that occur in these areas.

Chapter III covers the Canadian Precambrian Shield. Its subdivisions are: 1, Yellowknife-Great Bear Lake Area; 2, Manitoba and Saskatchewan; 3, Red Lake-Patricia Area; 4, Little Long Lac-Sturgeon River Area; 5, Steep Rock-Michipicoten-Goudreau Area; 6, Porcupine-Ramore Area; 7, Sudbury Area; 8, Matachewan-Kirkland Lake-Larder Lake Area; 9, Rouyn-Chibougamau Area: Western Part; 10, Rouyn-Chibougamau Area: Eastern Part. Each part covers a natural unit and most of them are preceded by a general paper covering the larger structural features. This is followed by descriptions of the individual mines of the district. This chapter constitutes about three-quarters of the book since most Canadian Mines are in the Shield.

Chapter IV in its two parts covers The Eastern Townships and Gaspé, and Nova Scotia.

Suitable diagrams, maps, or photos accompany most of the papers. The coverage is so complete that the volume is essentially a compendium of the geology of Canada, and it affords a ready reference to the geology of any mine in Canada.

All geology owes a debt to the Committee and the Canadian Institute.

ALAN BATEMAN.

Physical Geology, 3rd Edit. By C. R. LONGWELL, ADOLPH KNOPF AND R. F. FLINT. Pp. 602; figs. 365. John Wiley & Sons, New York, 1948. **Price, $5.00.**

This best of textbooks of physical geology appears in a new edition, the third. The first edition appeared 16 years ago and it was successor to several editions of

its predecessor, Physical Geology, by L. V. Pirsson. It is now used in 135 North American colleges.

The new edition has undergone real revision. The chapter headings and appendices remain as before, but a new chapter on "The Method and Scope of Geologic Study" has been added. More emphasis has been placed on principles and less on details, and parts of many chapters have been recast and newer material added.

One is struck immediately by the illustrations. Not only has the number been increased but most of the older ones have been replaced by new ones. Many block diagrams have been inserted, others have been redrawn, and particularly most of the photographs have been replaced by large bleed cuts that extend the full width of the page. The choice of these has been excellent. These pictures give the impression of an entirely new book, rather than of a new edition.

The publishers have introduced an innovation in that they have provided an accompanying set of kodachrome slides to illustrate most aspects of the subject matter.

Both authors and publishers deserve congratulations.

Cobalt. By ROLAND S. YOUNG. Pp. 181; illust. Reinhold Publishing Corp. New York, 1948. Price, $5.00.

This volume is one of the American Chemical Society Monographs on chemical subject and the author is the Chief Research Chemist of the Rokana, N'Changa, and Rhodesia Broken Hill mining companies in Northern and Southern Rhodesia—which companies are large producers of by-product cobalt.

This volume deals with cobalt from the standpoint of the chemist, metallurgist, mining engineer, geologist, physicist, biochemist, and soil technologist and appears to be a complete coverage of cobalt. The contents are: historical; occurrence; metallurgy; chemical, physical and mechanical properties; cobalt in ferrous alloys, non-ferrous alloys, in powder metallurgy, electroplating in glass and ceramic industries; catalytic behavior; biological and biochemical relationships; and analysis of cobalt. As the contents indicate, it is a complete monograph—and a welcome one.

Submarine Geology. By FRANCIS P. SHEPARD. Pp. 338; figs. 106. Harper and Bros. New York, 1948. Price, $6.00.

Carey Croneis in his Introduction to this book says "Indeed, in the strictest sense, this is the first actual text in any language on the too little known geology of the water-washed three-quarters of the face of the earth." So much has been learned lately of the floors of the oceans by the author of this book, by Mr. Ewing, and by others, that a compact text book dealing with this subject is welcomed.

The volume deals with the ocean floor, coral reefs, submarine canyons, currents and shorelines and the continental shelves. The 12 chapters give some idea of the contents, namely: Introduction and History; Methods of Exploring the Ocean Floor; Waves and Currents; Classification of Sea Coasts and Shorelines; Beaches and Sand Shifting along the Shores; Continental Shelves—Topography and Sediments; Origin and History of the Continental Shelves; Continental Slopes; Submarine Canyons; Coral Reefs; The Floor of the Deep Oceans; Summary and Economic Applications.

The last chapter is of particular interest to engineering geologists and to petroleum geologists who are today active in probing the continental shelves for oil.

The discussion of the fascinating and perplexing submarine canyons regarding which Dr. Shepard has done so much will interest everyone.

The book is nicely printed and well illustrated with clear charts and drawings. The author and publishers are to be congratulated.

Geologic Guidebook along Highway 49. Prepared under the direction of OLAF P. JENKINS. Pp. 164; 12 maps; 239 photographs. Olaf P. Jenkins, Chief, State Division of Mines, Ferry Building, San Francisco 11, California. Price, $1.00.

All geologists and especially students of ore deposits will want to have with them this cheap and handy guide to the Mother Lode Country when they visit California. Though the student of ore deposits would like to have available a discussion of the genesis and characteristics of the ore deposits, such material has been wisely left out. He, like all others, will find the chapter entitled "Geologic Maps and Notes Along Highway 49," with its 12 convenient geologic strip maps, a useful and handy guide to the topography, geology, mines, and buildings. The other chapters relate succinctly the geologic and human history of the region. A chapter on early buildings should awaken geologists to a subject which when closely studied yields the history of the past in its most arresting form, and is related to their own field. The book is lavishly illustrated and the whole format is excellent.

FRANCIS G. WELLS.

BOOKS RECEIVED.

ALAN T. BRODERICK.

U. S. Geological Survey—Washington, 1948.

Bull. 954–B. Geology and Chromite Deposits of the Camagüey District, Camagüey Province, Cuba. D. E. FLINT, J. F. DE ALBEAR AND P. W. GUILD. Pp. 28; figs. 3; colored geol. maps 2. *Ore occurs as irregular masses in serpentinized peridotite and dunite with minor amounts of gabbro and anorthosite. Larger ore bodies believed to be fragments of former deep-seated gravity differentiated sheet which was broken during movement to present position. Gravity survey successful in ore discovery; magnetic methods worthless.*

Bull. 954–C. Aluminous Lateritic Soil of the Republic of Haiti, W. I. S. S. GOLDICH AND H. R. BERGQUIST. Pp. 50; pls. 3; figs. 4; tbls. 17. *Estimate 10 million long tons 46.8% Al_2O_3; 0.5% SiO_2; 2.8% TiO_2; 21.9% Fe_2O_3; 0.6% P_2O_5; 0.5% MnO_5. Since underlying limestones contain less than 0.1% alumina, deposits are believed derived from another source. Composition suggests igneous parent material of intermediate composition.*

Prof. Pap. 213. Gold Deposits of the Southern Piedmont. J. T. PARDEE AND C. F. PARK, JR. Pp. 156; pls. 60; figs. 42. *A comprehensive report based on the writers' field work and on information gleaned from many sources.*

U. S. Bureau of Mines—Nov. 1947–Sept. 1948.

R. I. 4121. Investigation of the Mount Eielson Zinc-Lead Deposits, Mount McKinley National Park, Alaska. N. M. MUIR, B. I. THOMAS AND R. S. SANFORD. Pp. 13; figs. 5; tbls. 2. *Replacements and fillings in Paleozoic sedimentites near a mass of granodiorite. Report gives results of sampling and metallurgical testing.*

R. I. 4124. Blue Ledge Copper-Zinc Mine, Siskiyou County, Calif. R. J. HUNDHAUSEN. Pp. 16; figs. 3. *Small replacement bodies along shears in schists. Report gives results of drilling, sampling and metallurgical testing.*

R. I. 4207. Margerum Bauxite District, Colbert County, Ala. DON M. COULTER. Pp. 10; figs. 3; tbl. 1; drill-hole analyses. *37 drill holes totalling 2,851 feet show 12 deposits containing 12,000 tons of grade "C" bauxite and 175,000 tons of grade "D." Believed result of bauxitization of kaolin lenses in Cretaceous Tuscaloosa formation.*

R. I. 4266, 4267, 4268. Investigation of Arkansas Bauxite. Vols. XVI–XVIII. M. C. MALAMPLY, G. K. DALE, T. M. ROMSLO, A. H. REED, JR., AND A. OLLAR. Pp. 294; figs. 15; drill-hole logs and analyses. *Factual data. Hole-by-hole description of the hundreds drilled on this project. See Vol. I, R. I. 4251, for general discussion of geology, exploration and development methods, laboratory procedures, etc.*

R. I. 4317. Investigation of the Crescent Lead and Zinc Mine, Iowa County, Wis. M. HOWARD BERLINER. Pp. 6; fig. 1; drill-hole logs and analyses. *24 holes totalling 1290 feet outline favorable-looking synclinal structure but no ore.*

R. I. 4325. Investigation of Rex Zinc Mine, Howell County, Mo. HOMER J. BALLINGER. Pp. 11; figs. 2; drill-hole logs and analyses. *4 churn-drill holes totalling 880 feet show mixed oxide and sulphide mineralization below old workings in oxide ore.*

R. I. 4326. Investigation of the Critchfield Manganese Deposit, Huntingdon County, Pa. W. H. KERNS AND R. S. SANFORD. Pp. 7; figs. 2; drill-hole logs. *Small, low grade deposit of nodular manganese in clay—a weathered phase of the Gatesburg formation.*

R. I. 4327. Investigation at the Fairplay Zinc and Lead Area, Grant County, Wis. JAMES V. KELLY. Pp. 5; tbls. 2; fig. 1. *15 holes totalling 2,457 feet drilled to investigate favorable structural trend. No ore found.*

R. I. 4328. Investigation of the Ore Hill Zinc-Lead Mine, Grafton County, N. H. H. P. HERMANCE AND MCHENRY MOSIER. Pp. 13; tbls. 6; figs. 10. *Some of the 14 holes totalling 4,899 feet drilled down dip from old mine on schist bedding plane vein show narrow good grade mineralization.*

R. I. 4329. Investigation of Kiowa County Clays, Kiowa County, Okla. C. C. KNOX. Pp. 18; tbl. 1; figs. 2; drill-hole logs and analyses. *45 holes totalling 1,723 feet outline enormous deposits of shallow clay averaging over 20 but under 30% alumina. Clay is result of Precambrian (?) weathering in place of gabbro and anorthosite. Tests show clay's alumina content cannot easily be increased sufficiently for any alumina process.*

R. I. 4332. Investigation of the Dempsey Zinc-Lead Mine, Washington County, Mo. W. D. MCMILLAN, M. M. FINE AND H. KENWORTHY. Pp. 16; tbls. 3; figs. 5; drill-hole logs and analyses. *20 drill holes totalling 1,309 feet find only erratic, weak mineralization.*

R. I. 4350. Investigation of the Blewett Zinc-Lead Deposit, Jo Daviess County, Ill. STEPHEN P. HOLT. Pp. 36; figs. 7; drill-hole logs and assay. *Extensions of old ore body found by 8 churn-drill holes and 9 diamond drill holes.*

Arkansas Division of Geology—Little Rock, 1948.

Bull. 12. Molybdenum in Magnet Cove, Arkansas. DREW F. HOLBROOK. Pp. 16; figs. 2; map 1. *400 × (10–35) foot area of fractures in pyroxenite*

filled with feldspar, quartz, pyrite and molybdenite. Average surface grade of wider veins in part of area is 1.07% MoS_2. Tonnages not estimated because of unreliability of drill sampling.

Bull. 13. Titanium in Southern Howard County, Arkansas. DREW F. HOLBROOK. Pp. 16; figs. 2. *Small tonnage of ilmenite-bearing sand in the Upper Cretaceous Tokio formation.*

Illinois Geological Survey—Urbana, 1948.

Rep. Inv. 133. Correlation of Domestic Stoker Combustion with Laboratory Tests and Types of Fuels. III, Effect of Coal Size upon Combustion Characteristics. ROY J. HELFINSTINE. Pp. 47; tbls. 45; figs. 28.

Rep. Inv. 135. Subsurface Correlations of Lower Chester Strata of the Eastern Interior Basin. DAVID H. SWANN AND ELWOOD ATHERTON. Pp. 18; tbls. 4; figs. 6. *"Aux Vases" sand and Rosiclare sand of Ste. Genevieve are equivalent; "Benoist" (Yankeetown), Bethel, and Sample sands are successively younger, not equivalent; Indiana and Kentucky Cypress is younger than Illinois Cypress; Downey's Bluff is equivalent to basal Paint Creek and to upper Paoli limestone of Indiana; Levias ls. and part of the Shetlerville (Renault) form continuous limestone sequence overlying "Aux Vases" and Rosiclare sandstone.*

Circ. 146. Agstone Used in Illinois in 1947. WALTER H. VOSKUIL AND ETHEL M. KING. Pp. 10; tbls. 5; map 1. *Over 5 million tons of ground limestone and dolomite used for soil improvements.*

Press Bull. Ser. 58. Oil and Gas Development in Illinois in 1947. ALFRED H. BELL AND VIRGINIA KLINE. Pp. 53; tbls. 7; figs. 2.

Kansas Geological Survey. 1948.

Bull. 73. Ground-Water Resources of Republic County and Northern Cloud County, Kansas. V. C. FISHEL. Pp. 191; pls. 12; figs. 6; tbls. 22.

Kansas Rocks and Minerals. LAURA LU TOLSTED AND ADA SWINEFORD. Pp. 54; photos and figs. 23. *Non technical summary.*

Research Program of the Michigan College of Mining and Technology, 1927–1944. A. K. SNELGROVE. Pp. 59; figs. 11. Michigan Coll. Min. Tech. Bull., Vol. 21, No. 4, Houghton, 1948.

New Hampshire Planning and Development Commission—Concord, 1948.

Mineral Resource Survey Pt. 9. Mineral Composition of New Hampshire Sands. J. W. GOLDTHWAITE. Pp. 7; tbl. 1; map 1.

Pt. 10. Glacial Till in New Hampshire. LAWRENCE GOLDTHWAITE. Pp. 11; figs. 5; tbls. 2. *Concludes till density is controlled by water content at time of deposition rather than by weight of ice or size distribution of components.*

Annual Report 3, July, 1947–June 30, 1948. E. C. ANDERSON. Pp. 56. New Mexico Bur. Mines & Min. Res., Socorro, 1948.

Ohio Water Resources Board—Columbus, 1948.

Bull. 12. The Water Resources of Montgomery County, Ohio. STANLEY E. NORRIS. Pp. 83; pls. 48; tbls. 31. *Largest supplies from glacial aquifers below present streams.*

Bull. 16. Ground-Water Levels in Ohio, 1947. DONALD W. VAN TUYL AND PAUL KASER. Pp. 62; pls. 30; tbls. 20.

Industrial Limestones and Dolomites in Virginia: Northern and Central Parts of Shenandoah Valley. RAYMOND S. EDMUNDSON. Pp. 195; pls. 19; figs. 5; tbls. 21. Virginia Geol. Survey Bull. 65, University, 1945 (1948).

Stratigraphic Sections of Jurassic and Cretaceous Rocks in the Jackson Hole Area, Northwestern Wyoming. J. D. LOVE, D. C. DUNCAN, H. R. BERGQUIST AND R. K. HOSE. Pp. 48; figs. 2. Wyoming Geol. Survey Bull. 40, Laramie, 1948. *4 detailed Cretaceous and 2 partial Upper Jurassic sections.*

Report of the Gold Coast Geological Survey Department, 1946–1947. Pp. 10. Accra, 1948. *Report on year's field and office work.*

Compléments à la Bibliographie Géologique de l'Afrique Centrale de 1937—Congo Belge. A. JAMOTTE. Pp. 38. Paris, 1948. *Unannotated.*

Diatomaceous Deposits in the Union of South Africa with Special Reference to Kieselguhr. Pt. 1, Geology and Economic Aspects. L. E. KENT. **Pt. 2, The Diatom Flora.** A. W. ROGERS. Pp. 260; pls. 14; figs. 16. S. Africa Geol. Survey Mem. 42, Pretoria, 1947. *Fresh-water deposits formed in swampy areas during period of higher water due to either greater rainfall or colder climate and resulting decreased evaporation during the late Pleistocene.*

Annual Report of the Uganda Geological Survey Department for 1945. Pp. 40; tbls. 3. Entebbe, 1948. *Report on the year's field and office work.*

The Geology of the Country Around Mwanza Gulf. G. M. STOCKLEY. Pp. 25; tbls. 2; map 1. Tanganyika Geol. Div. Pap. 29, Dodoma, 1947.

Annual Report for 1947. Pp. 4. Northern Rhodesia Water Development and Irrigation Dept. Lusaka, 1948.

Departmento Nacional da Produçao Mineral—Rio de Janeiro, 1947–1948.

Relatório Anual do Diretor, 1943. ANIBAL ALVES BASTOS. Pp. 81.

Relatório Anual do Diretor, 1945. M. G.-OLIVEIRA ROXO. Pp. 82.

Nota Prel. 38a. Classification of the Gondwanic Rocks of Paraná, Santa Catarina, and Rio Grande do Sul. MACKENZIE GORDON, JR. Pp. 19.

Nota Prel. 43. Areia de Fundiçao de Macaé. ALBERTO RIBEIRO LAMEGO. Pp. 15; figs. 4. *Founding sands of Macaé.*

Nota Prel. 45. Ocorrencia de Rutilo Colombiano no Brasil. ELYSARIO TAVORA AND EVARISTO P. SCORZA. Pp. 9; figs. 3; tbl. 1. *Occurrence of Colombian rutile in Brazil.*

Bol. 81. Cobre em Pedra Branca, Picui-Paraiba. ONOFRE PEREIRA CHAVES. Pp. 49; tbls. 7; photos 7; figs. 2. *Estimate 150,000 tons of less than ½ percent Cu in pegmatites and a selectively replaced amphibolite layer in schists.*

Bol. 82. Relatório da Diretoria, 1946. ALBERTO ILDEFONSO ERICHSEN. Pp. 118; numerous tables, plates, photos, figures. *Mineral-by-mineral listing of progress during 1946.*

Avulso 76. Aspectos Científicos e Técnicos do Controle da Energia Atomica. Pp. 31; figs. 2. *Portuguese translation of Report No. 3 of the U. N. Atomic Energy Commission.*

Ontario Department of Mines—1947–1948.

Map No. 1947–1. Township of Hearst and a Portion of the Township of McFadden. J. E. THOMSON. 32 x 41″, colored, scale 1″ = 1000′. *Detailed geology of area south of Larder Lake.*

Map No. 1947–2. Township of Beatty, District of Cochrane, Ont. J. SATTERLY AND H. S. ARMSTRONG. Colored, 32 x 35″, scale, 1″ = 1000′.

P. R. 1948–8. Report on Some Radioactive Mineral Occurrences in Cardiff and Monmouth Townships, Haliburton County, Ont. S. E. WOLFE AND NELSON HOGG. Pp. 13; figs. 7. *Small amounts of uraninite in calcite-fluorite-apatite "vein-dikes." Use of Geiger-Mueller counter in prospecting described.*

P. R. 1948–9. Report on a Pitchblende Occurrence at Theano Point, Lake Superior, Ontario. J. SATTERLY AND D. F. HEWITT. Pp. 3; map 1. *Occurrence about 70 miles north of Sault Ste. Marie. Uraninite-bearing fissure fillings in granite and gneiss, in footwall of diabase dike. Relation of veins to dike believed structural, not genetic. Widest uraninite showing, 6 inches, highest grade, 61.6% UO_2. Further exploration needed to prove whether deposits are large enough to be economically workable.*

Soils Quarterly, Vol. 6, No. 2, June 1947. Pp. 38; figs. 4. Nanking. *Bilingual (Chinese-English) publication concerned with soil science in China.*

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Geology of the Country Around Barnsley. G. H. MITCHELL, J. V. STEPHENS, C. E. N. BROMEHEAD, D. A. WRAY, AND R. CROOKALL. Pp. 182; figs. 33; pls. 2. Great Britain Geol. Survey, London, 1947. *Includes large part of South Yorkshire coalfield. Stratigraphy, structure, paleontology, several structure contour and isopach maps.*

Die Sogenannten Steinsalz-Pseudomorphosen als Kristall-Relikte (The So-called Rock Salt Pseudomorphs as Crystal Relicts). OTTO LINCK. Pp. 44; pls. 3; figs. 5. Frankfurt A. M., 1946.

Vergleichende Petrographie Oolithischer Eisenerze (Comparative Petrography of the Oolitic Iron Ores). GEORG BERG. Pp. 128; microphotos 22; figs. 129. Berlin, 1944. *Detailed work based on study of 940 thin sections. Exhaustive study of the internal structures and minerals of oolites.*

Report of the Malayan Union Geological Survey Department for 1947. HAROLD SERVICE. Pp. 39; fig. 1. Kuala Lumpur, 1948. *Mineral-by-mineral report of year's field and office work.*

Geological Map of Malaya, 1948. GEOL. SURVEY STAFF. Colored, 24″ x 32″, scale 1″ = 12 miles.

Newfoundland Geological Survey—St. John's, 1948.

Bull. 23. Geology and Mineral Deposits of the St. Lawrence Area, Burin Peninsula, Newfoundland. RALPH ERSKINE VAN ALSTINE. Pp. 64; pls. 2; tbls. 6; figs. 37. *Describes important fluorspar deposits which are strike-slip to normal fault fissure fillings in Devonian (?) granite, rhyolite and lamprophyre.*

Bull. 24. Geology and Mineral Deposits of Southern White Bay. FREDERICK BETZ, JR. Pp. 26; pls. 7; tbls. 2. *General geology of area of Precambrian to Mississippian rocks. Minor quartz-gold fault fillings (?).*

Soviet Land, the Country, its People, and their Work. G. D. B. GRAY. Pp. 324. Adam and Chas. Black, London, and McMillan Co., New York, 1948. Price, $3.00. *A description of Russia and its people by an English geographer who has travelled widely in Russia. Covers also climate, soil and vegetation, agriculture, population and nationalities. A good readable reference book, well illustrated.*

SOCIETY OF ECONOMIC GEOLOGISTS

*Abstracts of papers to be presented at the Twenty-ninth Annual Meeting in conjunction with the American Institute of Mining and Metallurgical Engineers, San Francisco, February 1949.**

THE RELATIONSHIP OF CONTACT-METAMORPHIC TUNGSTEN DEPOSITS TO REGIONAL GEOLOGY IN THE BISHOP DISTRICT, CALIFORNIA.[1]

PAUL C. BATEMAN.

The metamorphic rocks in the Sierra Nevada near Bishop, Calif., occur as (1) large roof pendants, (2) thin, discontinuous septa, or "screens" between intrusive masses of batholithic size, and (3) relatively small inclusions, which are especially abundant in bodies of dioritic or gabbroic composition. In all three settings, tungsten deposits are found where calcareous rocks are in contact with intrusive rocks. The distribution and shapes of the ore bodies, and of the ore shoots within them, are controlled by (1) irregularities in the igneous contacts, (2) bedding in the metamorphic rock, and (3) fractures in the metamorphic rock. The most productive single ore body in the district is known to have a vertical extent several times greater than its longest horizontal dimension, and probably represents a channel through which upward-moving mineralizing solutions traveled.

VEIN FEATURES IN THE OUACHITA MINERAL PROVINCE, ARKANSAS.[1]

A. E. J. ENGEL.

Within the widespread vein system of the Ouachita Mountains, Ark., many veins exhibit features attributable to (1) deformation preceding and accompanying vein formation, (2) influences of diverse wall rocks, and (3) movements of vein-forming solutions.

Most veins follow incipient or well-defined longitudinal fractures closely related to fold systems in quartzites, slates, and thin limestones of the Ouachita anticlinorium. Many veins are fissure fillings. Locally, displacements of opposite walls of veins during mineralization have produced lineated and reticulated mats of quartz crystals which indicate relative directions of movement.

Veins, with or without inclusions, and with: (1) one or more dominant mineral or chemical components in common with wall rocks and (2) walls of irregular, nonmatching patterns which lack offsets, are interpreted as formed by replacement or recrystallization of wall rock.

Recrystallization of quartzite into quartz veins is shown by relict sand grains. Some of these veins are interrupted at contacts with shale whereas others extend into or cross shales. These veins may be vuggy and essentially free of disseminations or selvages of carbonaceous matter, clay, and iron oxides that are dispersed throughout the wall rock. Accordingly, introduction and removal of constituents is implied.

* Footnote 1 indicates published by permission of the Director, U. S. Geological Survey.

Some veins in slates show phantom textures reflecting replacement. Many contain adularia, dickite, and chlorite. Veins cutting calcareous beds show abundant coarse calcite. Some or all the major constituents for certain minerals were derived from the adjoining wall rock and incorporated in the veins, producing contrasting assemblages in quartzites, shales, and limestones. At some lithologic contacts there is sufficient unidirectional carry-over of constituents derived from one wall rock, into the vein in a contrasting wall rock, to suggest a direction of movement for vein-forming solutions. The flow patterns indicated are complex, but in general they corroborate the assumption made from fabric studies of asymmetrical quartz crystals, that the solutions were dominantly rising, although locally evidences for lateral and even downward movements of vein solutions appear.

UNIFORMITARIANISM AND THE IDEAL VEIN.

HARRISON SCHMITT.

Construction of the ideal vein with the assumption that the theory of uniformitarianism applies throughout earth history is questioned. Certain data suggest that some types of mineral deposition may be unique with time. The data given by Jeffreys and Daly strongly indicate that the earth's crust has changed fundamentally with time. Present day theory implies that vertical zoning should be common; actually it is rare except in the special cases discussed. This suggests the need for competing hypotheses of "mineralization" genesis. The classification of mineral deposits by metal content has of course long been unsatisfactory. For example, Tertiary deposits of epithermal character contain commercial deposits of metals which would normally be said to be characteristic of the "deep zone." Although the majority of metals seem to persist in the various ore mineralizations throughout earth history certain metals and other elements may be quantitatively unique with time. Mercury and possibly tellurium seem characteristic of late time.

GEOCHEMICAL PROSPECTING FOR ORES: A PROGRESS REPORT.[1]

H. E. HAWKES.

Methods of prospecting for mineral deposits by means of chemical studies of residual soil, alluvium, glacial moraine, vegetation, and natural water were first applied on a systematic scale in Scandinavia and Russia about 12 years ago. Since the war, work in this field has been undertaken by several independent groups in the United States and Canada, principally the Geochemical Prospecting Unit of the U. S. Geological Survey.

Best results, including work both here and abroad, have been obtained by systematic analysis of zinc in residuum; copper in alluvium; tin in residuum, alluvium and vegetation; and tungsten in vegetation. Promising but not conclusive results have been obtained for zinc in water, glacial moraine, and vegetation; for copper in residuum; for molybdenum and lead in residuum; and for cobalt, nickel, and gold in vegetation. Generally unfavorable results have been obtained for copper and lead in water and vegetation. In addition, studies of plant ecologies in relation to copper-rich soils, and studies of toxicity symptoms in vegetation as related to zinc-rich soils appear to be promising. All results indicate that the geochemical approach is no panacea, but must be applied with careful attention to the effect of local climatic, topographic, and geologic conditions.

The current geochemical prospecting program of the Geological Survey includes

research on the development of a series of rapid, simple, and sensitive analytical tests for ore metals in soil, water, and vegetation, suitable for use under field conditions.

OXIDATION AND ENRICHMENT IN THE SAN MANUEL COPPER DEPOSIT, ARIZONA.[1]

G. M. SCHWARTZ.

The San Manuel copper deposit of southwest Arizona was discovered by drilling done under the strategic-minerals program of the United States Government. The ore is disseminated throughout a large zone in quartz monzonite (Oracle granite) of pre-Cambrian age and monzonite porphyry of Tertiary (?) age. Oxidation and enrichment have played an important part in development of present conditions within the deposit.

The oxidation and enrichment took place during an erosion cycle that preceded the present cycle and probably the last two cycles. A conglomerate, here referred tentatively to the Gila conglomerate, was laid down on the eroded and oxidized ore deposit; in some places the conglomerate reaches a thickness of over 1,000 feet and perhaps much more. The age of the Gila conglomerate is believed to be late Pliocene and possibly Pleistocene, but solution of the problem of the correlation of the conglomerate in the San Manuel area requires detailed work over a large area. Extensive tilting and faulting followed the deposition of the conglomerate. Alluvial slope gravels were laid down across the eroded edges of the conglomerate, and later faulting affected both gravels and conglomerate.

The zones of oxidation and enrichment are not related to the present water table. The depth to the bottom of the oxide zone ranges from 285 feet to 1,630 feet. Differences in surface altitudes and probably tilting of the original oxide zone account for the great differences in depth.

Chrysocolla is the most important copper mineral in the oxide zone, which contains tens of millions of tons of low-grade material averaging about 0.70 percent copper.

Sulfide enrichment was variable. In general the increase in copper content averages only a few tenths of a percent. Some holes in the eastern part of the area show a relatively thin zone that was enriched fairly heavily. An unusual feature is the presence of considerable disseminated native copper and goethite in the sulfide zone.

THE GEOLOGY OF THE MASSIVE SULFIDE DEPOSITS AT IRON MOUNTAIN, SHASTA COUNTY, CALIFORNIA.[1]

A. R. KINKEL, JR., AND J. P. ALBERS.

The Iron Mountain mine is in the rugged Klamath Mountains 15 miles northwest of Redding, California. The ore bodies are large lenses of massive pyrite containing chalcopyrite and sphalerite, with minor amounts of gold and silver.

The oldest rocks in the area are the basic and intermediate flows of the Copley meta-andesite, which is probably Lower Devonian in age. They are overlain by the silicic flows and pyroclastics of the Balaklala rhyolite of Diller. A subsidence in Middle Devonian time initiated the deposition of shales, tuffs, and limestones of the Kennett formation, followed by the shales and conglomerates of the Bragdon formation during Mississippian time. Later the rocks were folded, locally sheared, and intruded by quartz diorite.

The massive sulfide deposits occur in Diller's Balaklala rhyolite. Individual ore bodies at Iron Mountain range in size from a few thousand tons to over 5 million tons and are faulted parts of an originally continuous ore body which was 4,500 feet long. The ore is a replacement of a porphyritic rhyolite. Tuff and agglomerate layers appear to have been unfavorable for ore deposition. Within the ore bodies replacement is almost complete, and at their boundaries there is a sharp change to unreplaced rhyolite. All of the massive sulfide ore contains some copper and zinc, but minable bodies of copper-zinc ore are closely associated with feeder channels along faults that existed prior to formation of the ore.

For the district the main ore controls are a gently pitching anticlinorium, and impervious shales which lie a few hundred feet above the ore zone. The Iron Mountain ore body occurs where a synclinal trough in the volcanics is cut by steep feeder channels.

GEOLOGY OF THE CERRO GORDO MINE AREA, INYO COUNTY, CALIFORNIA.[1]

CHARLES W. MERRIAM.

The important lead ore bodies at the Cerro Gordo mine are found in a Devonian unit of marble and interbedded quartzite, on the east side of a north-trending master fault separating the Devonian rocks from a lower Carboniferous unit of black shale and silicated limestone. North-trending faults are particularly characteristic of this portion of the Inyo Mountains.

Fissuring sympathetic to the master fault, as well as local bedding features of the Devonian quartzitic unit, present evidences of ore control in two major ore chimneys. In the Cerro Gordo area generally the Devonian quartzitic unit appears to be unusually favorable for lead-zinc ore occurrence and suggests possibilities for future exploration at the mine and in neighboring areas.

NATIONAL MINERAL RESOURCE APPRAISAL.[1]

S. G. LASKY.

Attempts to assemble and use available information about the nation's mineral resources, in solving many critical problems facing the country, have demonstrated that present knowledge is inadequate. We need wider coverage and integration, more continuous over-all attention, and more penetrating analysis and interpretation than anything yet provided.

A comprehensive appraisal must start with estimates of the material in the ground, including an estimate of probable future discovery, and including also not only material minable under current conditions but material that may become usable in the future. These estimates must be supported by an analysis of the various factors—geologic, technologic, economic, and political—that influence the possible entry of the material into commerce and use.

A logical way of summarizing the data is in terms of production and consumption, rather than in terms of absolute tonnages. But to help overcome the hazards and deficiencies inherent in this statistical approach, there should also be qualitative appraisals of commodity self-sufficiencies, outlook for technologic improvement, and the like. Allowing for future requirements poses a special difficulty, particularly with respect to deciding what yardstick to apply to estimates of reserves, in order to interpret them in terms of national self-sufficiency.

The job is complex and difficult. Moreover, it will be with us as long as we use metals and minerals, and the need for it will become increasingly acute as our raw-material resources are progressively depleted.

ORIGIN OF THE BENDIGO SADDLE REEFS WITH COMMENTS ON THE FORMATION OF RIBBON QUARTZ.[1]

F. M. CHACE.

Several textural varieties of quartz, together with ore textures and structural relations, indicate that (1) open-space filling, (2) replacement, and (3) growth by accretion were active processes in the formation of the saddle reefs and related quartz bodies of the Bendigo goldfield, Australia. The relative importance of each process varied with the type of quartz body: spurs and the central parts of saddle reefs formed by open-space filling; leg reefs, "backs," fault reefs, inner reefs, and some parts of saddle reefs formed by replacement; all types of quartz bodies were affected by the process of accretion, which included intermineralization fracturing, brecciation, vein reopening, and recementation by quartz. Permeability was thereby maintained and deposition of late gold facilitated. The position of the textural varieties of quartz in the fracture pattern, which localized the quartz bodies in the folded rocks, is a key to the type of stress active in the formation of each body and indicates its method of emplacement.

Book structure, ribbon structure, and "crinkly banding" probably resulted primarily from the replacement of previously sheared or foliated zones in wall rock; the individual leaves and ribbons are usually residues from the replacement process. In addition to replacement at Bendigo, dilation of foliated rock by spreading of leaves and ribbons probably took place. The subsequent deposition of quartz in the open spaces resulted in laminated structures. Spreading apart of the foliation planes occurred along bedding-plane faults as a consequence of tensional stresses which resulted from the reverse faulting superimposed on the folded rocks.

THERMAL SPRINGS AND THEIR POSSIBLE SIGNIFICANCE IN THE FUTURE DISCOVERY OF ORE DEPOSITS.[1]

DONALD E. WHITE, GEORGE A. THOMPSON, AND W. W. BRANNOCK.

Thermal springs afford opportunity for the geochemical study of problems related to ore deposits. Such study suggests applications to the search for ore.

Thermal springs are divided into three main classes: (1) volcanic, in which part of the water supply, some of the dissolved material, and most of the heat are from a volcanic source; (2) nonvolcanic, in which neither water nor heat is of direct volcanic origin; and (3) intermediate, in which the water is meteoric but the heat is in part volcanic.

At Steamboat Springs, Nev., some springs and hot wells discharge water, at or near boiling temperature, which is supersaturated in respect to CO_2 and possibly other constituents. This suggests the possibility that metastability should be given greater consideration in studies of ore deposition.

Topography and water-table relationships are important in determining which near-surface structures will be utilized by rising hot water carrying ore substances and which by descending meteoric water.

Thermal springs also afford data on the origin and significance of rock alteration.

THE UTILIZATION OF INDUCED STREAM INFILTRATION AND NATURAL AQUIFER STORAGE AT CANTON, OHIO.

RAPHAEL G. KAZMANN.

The exploratory geologic program and the hydrologic studies made to insure the success of Canton's new infiltration water supply are described herein. By means of stream flow measurements combined with flow-duration curves of another stream, a synthetic flow-duration curve was computed for the West Branch of Nimishillen Creek and the available quantity of water determined.

Two separate aquifers were found in the area. A pumping test was made in each formation and the results were used as a basis for determining the number and type of horizontal collectors needed to develop 10 mgd of firm water. Dual-purpose collectors were designed and constructed to infiltrate up to 18 mgd when available and to produce 10 mgd at all times. Because it is a pioneer installation the Ohio Water Resources Board and the City of Canton are making a careful study of the field as it continues to operate. Preliminary data indicate that the system was conservatively designed and will probably yield more water than was originally planned.

GEOLOGY AND GROUND WATER RESOURCES OF CACHE VALLEY, UTAH, IDAHO.

PHILLIP F. FIX.

GEOLOGIC FEATURES CONTROLLING GROUND WATER OCCURRENCE AND YIELD IN THE WEST BASIN OF LOS ANGELES COUNTY, CALIFORNIA.

JOSEPH F. POLAND.

SCIENTIFIC NOTES AND NEWS

The Department of the Army has established a program of interest to economic geologists who are reserve officers. The objectives are: (1) to maintain the useful affiliation of economic geologists with the Organized Reserve Corps; (2) to provide peacetime Reserve assignments utilizing education, experience and skills; (3) to furnish mobilization assignments to utilize fully their talents; and (4) to adequately prepare such officers for mobilization. It is planned to submit research problems and projects in line with their scientific training. Reserve officers in teaching, industry or in research are eligible to make application for assignment to an Organized Reserve Research and Development Group, and groups will be organized where there are twenty or more qualified scientists. Inquiry about the organization of such a group should be made of the Unit Instructor, ORC, or Senior Army Instructor, ORC, in the locality in which he resides.

JACK V. EVERETT recently joined the technical staff of Pickands, Mather & Company in the capacity of geologist. He is stationed at Crosby, Minnesota, on the Cuyuna Range.

JOHN OWENS, geologist with the M. A. Hanna Company at Hibbing, was recently transferred to the Hanna operations at Crosby, Minnesota.

The U. S. Atomic Energy Commission announces that the Rifle, Colorado, plant of the United States Vanadium Corporation will offer to purchase uranium-bearing ores amenable to the Rifle process, from independent miners under provisions of a contract between the company and the U. S. Atomic Energy Commission. Up to this time the only ores processed at the Rifle plant have been from company-owned mines. The purchases will be on terms as favorable to producers as those previously set forth. As a result of the new contract, production at the Rifle plant is expected to be stepped up immediately and may perhaps be doubled. This plant serves an area remote from other uranium plants in the Colorado Plateau district.

The Department of Geology and Geography of the University of Tennessee is sponsoring a symposium on the mineral resources of the Southeast. Sessions will be held on the campus at Knoxville, on March 3, 4, and 5. Papers on the major metallic and non-metallic mineral products of the Southeast will be presented by invited speakers.

W. E. WRATHER, director of the Geological Survey, has been named chairman of a Committee on Geophysics and Geography by Dr. Karl T. Compton, chairman of the Research and Development Board.

The newly formed committee is a merger of the two former Committees on Geophysical Sciences and on Geographical Exploration. The group will study problems within the scope of the earth sciences, including weather and climate, strategic minerals, water supplies and contamination, the ocean, its circulation, and structure of the ocean floor. The committee will consider exploration expeditions and other types of field research. Its agenda includes the geographical nature and use of areas of the earth's surface with emphasis on the effect of physical and cultural elements of environment on man and his activities. Map content and

coverage also will be studied. Additional members of the committee include Samuel B. Morris, General Manager and Chief Engineer of the Department of Water and Power, Los Angeles; Horace Byers, Department of Meteorology, University of Chicago; P. E. James, Professor of Geography, Syracuse University; and Richard Joel Russell, Chairman, Department of Geography, Louisiana State University. Alternates to members include W. W. Rubey, Geological Survey, alternate to Dr. Wrather; Athelstan Spilhaus, Dean, School of Technology, University of Minnesota, alternate to Dr. Byers; Stephen B. Jones, Institute of International Studies, Yale University, alternate to Dr. James; and Lester E. Klimm, Chairman, Department of Geography, Wharton School, University of Pennsylvania, alternate to Dr. Russell.

Dr. H. E. Lansberg, formerly deputy executive director of the Committee on Geophysical Sciences will be executive director.

The U. S. Army announces that reserve commissions are now available to civilian qualified geologists, geographers, geophysicists and meteorologists, the rank depending upon qualifications and experience. Age limits are 21 to 55 years. Previous military experience is not required, but a bachelor's degree in the above mentioned subjects is necessary. For higher commissions additional qualifying education or progressive professional experience is necessary. Full details for commissioning of such civilians is given in the Army Circular No. 210 which may be obtained from the local Reserve Unit Headquarters or by writing Army Headquarters at New York, Baltimore, Atlanta, Chicago, Houston or San Francisco. Application forms and circulars may be obtained by writing to The Adjutant General, Department of the Army, Washington 25, D. C.

T. S. LOVERING, United States Geological Survey, delivered a university lecture at the University of Kansas on November 22, 1948, on the subject, "The Drive for Minerals."

The National Research Council, Fellowship Office, announces acceptance of applications for fellowships in the natural sciences for consideration this spring. The Fellowship programs are supported by the Rockefeller Foundation, the Radio Corporation of America, Merck and Co., the Carnegie Corporation, and the Atomic Energy Commission, and administered by the National Research Council. These provide for both predoctoral and postdoctoral research by U. S. citizens (in one case, Canadian citizens are eligible). The basic stipends for the predoctoral fellowships range from $1500 to $2400 per year and for the postdoctoral fellowships from $2500 to $5000 per year.

Applications and all required papers should be submitted during the month of January 1949. For application blanks and full information, address the Fellowship Office, National Research Council, 2101 Constitution Avenue, Washington 25, D. C.

T. FIELD of Duluth, Minnesota, and ORVIL R. WHITAKER of Denver, Colorado, have been appointed to the Atomic Energy Commission's Advisory Committee on Raw Materials. Other members of this Committee, formerly called the Advisory Committee for Exploration and Mining, are: Donald H. McLaughlin, president, Homestake Mining Co., Lead, South Dakota (chairman); Everette L. DeGolyer, petroleum geologist, DeGolyer and McNaughton, Dallas, Texas; Wilbur Judson, vice president and director, Texas Gulf Sulphur Co., New York, New York; Robert E. McConnell, McConnell Foundation, New York, New York; Fred Searls, Jr., president, Newmont Mining Corp., New York, New York; Clyde Williams, director, Battelle Memorial Institute, Columbus, Ohio.